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PROCESS REDESIGN OF THE NORWEGIAN NAVY MATERIEL COMMAND'S REPLENISHMENT OF INVENTORY ITEMS

by

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The Norwegian Navy Materiel Command must keep inventory in order to serve its customers. Service level is established as a measure of effectiveness on delivery from inventory. Long replenishment lead-time, with variability in both lead-time itself and lead-time demand, make it hard to achieve the desired service level. The lead-time becomes costly, both in form of holding cost of safety stock and in form of stock-outs.

Current inventory control policy used at the Materiel Command is presented, and compared to theoretical inventory control models. Computer simulation is used to measure current administrative lead-time at the Norwegian Navy Materiel Command. Two proposals for redesign of existing replenishment process are built as simulation models, and the effect on administrative lead-time and associated variability is measured. The first proposal is to consolidate two separate procurement offices into one. The second proposal is to introduce, and use electronic commerce in the replenishment process.

It is concluded that both redesign proposals will reduce administrative lead-time, variability and hence cost. Benefits from an introduction of electronic commerce will yield a yearly cost saving of at least 4,500,000 Norwegian Kroner, which is more than four times the savings of consolidation.

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PROCESS REDESIGN OF THE NORWEGIAN NAVY MATERIEL COMMAND'S REPLENISHMENT OF INVENTORY ITEMS

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Current inventory control policy used at the Materiel Command is presented, and compared to theoretical inventory control models. Computer simulation is used to measure current administrative lead-time at the Norwegian Navy Materiel Command. Two proposals for redesign of existing replenishment process are built as simulation models, and the effect on administrative lead-time and associated variability is measured. The first proposal is to consolidate two separate procurement offices into one. The second proposal is to introduce, and use electronic commerce in the replenishment process.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A. BACKGROUND

The Norwegian Defense Commission's Report of 1990 (Forsvarskommisjonen 1990) recommended a major change in the Norwegian defense structure. To be able to achieve the recommended change, a large investment in new and updated defense equipment was claimed necessary. To increase the budgetary spending on new material without increase in the annual defense budget, it became necessary to reduce logistical cost. This goal is more recently highlighted in the latest Norwegian Defense Study, published in the summer of 1997.

The reduction in logistics spending is to be gained without major reductions in mission capability, and hence operational availability for most existing defense units. It became clear at an early stage clear that one had to realize cost savings within all fields of logistics operations. In the "Long-Range Program Report" for the period 1994-1998 (Langtidsmeldingen 1994-1998), the savings goal was quantified to a 25 percent decrease in operational spending before the year 2002.

Because of this clear but unquestionably difficult goal, it becomes very important to recommend actions for reducing logistics spending, without reducing operational availability.

B. PROBLEM DESCRIPTION

The Norwegian Navy's inventory control model divides inventory items into three main handling categories., two of which are treated more or less manually. The last category is fully controlled by a computer system. Safety stock in all systems is based on lead-time and a desired protection level. Lead-time consists of the vendor's time to deliver an order and administrative lead-time. Administrative lead-time is defined as time spent by personnel, the computer system and in order transmittal (mail or fax), from the time that an item reaches its reorder point until the order is placed with a vendor, plus the time required for the item to be received from the vendor and made ready for issuing. Long lead-time results in high holding cost of safety stock.

According to Norwegian officials the administrative lead-time very often can be as long or longer than the vendors delivery time. If the Materiel Command can minimize unnecessary administrative delays, there will be substantial cost savings to the Norwegian Navy.

C. THESIS OBJECTIVE

The objective of the thesis is to investigate ways to reduce administrative lead-time. A simulation model is developed to evaluate performance of proposed process redesign efforts and impacts on administrative lead-time. The simulation language Arena is used. Impact of lead times and variation in lead times in the replenishment process is also discussed.

D. RESEARCH QUESTIONS

This thesis seeks answers to the following research questions:

1. What impact has replenishment lead-time theoretically in Inventory Management ?
2. What is current inventory control policy at the Norwegian Navy Materiel Command's wholesale level?
3. What is Business Process Reengineering (BPR) and Electronic Commerce (EC)?
4. Is it possible to reduce administrative lead-time, and how much can it be reduced through:
    - Consolidation of existing procurement processes, and
    - Introduction and use of electronic commerce?
5. What benefits can be gained at the Navy Materiel Command from introducing one of the redesign proposals?

E. SCOPE AND METHODOLOGY OF THESIS

The thesis will answer research question one and three through the use of existing research and current publications on the subjects, and by applying relevant examples to clarify

problem areas. Where possible, examples from the Norwegian Navy, and/or the US military will be applied.

Research question two will be answered based on telephone and electronic mail communication and interviews with Norwegian Navy officials currently at the Norwegian Navy Materiel Command, and further on data received from the Norwegian Navy Materiel Command in association with this thesis.

To answer the fourth question, a simulation model that mimics the existing replenishment process will be built in order to measure current administrative lead-time. Then a separate simulation model will be built for each of the two main redesign possibilities researched in this thesis, namely:

- Consolidation of the two procurement environments currently involved in the replenishment process, and
- Introduction and use of electronic commerce.

Analysis of the simulation results will be used to find, validate and quantify benefits from the two main redesign possibilities of existing replenishment processes.

F. LIMITATIONS AND ASSUMPTIONS

This thesis is concerned with how a reduction in administrative lead-time can be beneficial to the Norwegian Navy Materiel Command in general, and to the cost of replenishing and holding inventory in particular.

To be able to understand how lead-times influence the calculation of stock kept at the Navy Materiel Command, a review of the Navy's inventory control policy, and the theoretical inventory control policy that this model is built on, is given. Even though this thesis points out that the traditional inventory control model used by the Norwegian Navy might not be the best type to use in a military environment, it is not within the scope of this thesis to evaluate alternative inventory control policies.

It is assumed throughout this study that the two redesign proposals for replenishment of parts can be included at the Navy Materiel Command. No research has been done on organizational constraints that one or both of the proposals might meet at the Command.

This thesis must not be seen as an official view of the Norwegian Navy, but as independently conducted research on subjects that might be of interest to the Norwegian Navy.

G. POTENTIAL CONTRIBUTION

All reductions in lead-time that can be shown through the thesis will affect the number of inventory items calculated as safety-stock needed by the computer system, and also on the manually calculated safety stocks kept by the Materiel Command. This will be a considerable savings potential for the Norwegian Navy. Besides this, a consolidation of several existing processes and introduction of electronic commerce can save on personnel cost, or get a more efficient use of existing personnel.

H. THESIS OVERVIEW

Chapter II introduces two basic inventory control policies; the continuous and periodic policy. After the introduction of the two policies, the main purpose of the chapter is given through a theoretical evaluation of what impact lead-time can have on inventory management and control.

Chapter III takes the previous chapter's introduction to basic inventory policies further, by thoroughly comparing existing inventory control policy at the Norwegian Navy Materiel Command with the theoretical model in order to evaluate savings potential from a reduction in administrative lead-time.

Chapter IV briefly describes business process reengineering, and explains the approach chosen in this study.

Chapter V gives a background overview, and frame for the second redesign proposal of existing replenishment process at the Navy Materiel Command. The proposal in question is electronic commerce, more specifically, electronic commerce by using the Internet is in focus.

Chapter VI introduces simulation modeling as the tool used in this study for evaluation of the proposed redesign efforts. Different simulation models are presented, simulations conducted and results on administrative lead-time given.

Chapter VII gives a comparative analysis of the results found in Chapter VI, and presents costs and benefits of the two redesign proposals.

Chapter VIII contains conclusions and recommendations.

II. THE CONCEPT OF LEAD TIMES IN INVENTORY MANAGEMENT

A. INVENTORY CONTROL POLICIES

Demand for goods in the military as well as in any other organization, makes procurement and inventory operations an important part of the organization. Do organizations really need inventory operations as an important part of their organizations, as claimed above? Ballou [Ref.1:p.236] says:

> If demand for a firm's products were known for sure, and products could be supplied instantaneously to meet the demand, theoretically storage would not be required since no inventories would be held. However, it is neither practical nor economical to operate a firm in this manner because demand usually cannot be predicted exactly. Even to approach perfect supply and demand coordination, production would have to be instantly responsive, and transportation would have to be perfectly reliable with zero delivery time. This is just not available to a firm at a reasonable cost. Therefore, firms use inventories to improve supply-demand coordination and to lower overall cost.

Reducing overall cost, or finding the optimal combination of storage cost, ordering cost, and stock-out cost, is the main purpose of most inventory control policies and hence inventory control models. This is also the base for the Norwegian Navy's inventory control policy. It is important to recognize that the main purpose for holding inventory in the Navy is to support the fighting units so that they can accomplish their tasks optimally. This is done by deciding a goal for operational readiness for different end items that stored parts will support [Ref.2 P.70]. "The point to be made here is that, at times, the military's goal of maximizing operational readiness may be at odds with the classic inventory management goals of minimizing costs" [Ref. 3 P.31].

1. The Basic Inventory Models: Continuous and Periodic

The basic inventory models presented in this section are derived largely from Tersine [Ref. 9] and NAVSUP PUB 553 [Ref. 3].

The two basic model structures that have evolved from considerations of costs, management control, and accounting practices are the continuous review and periodic review systems.

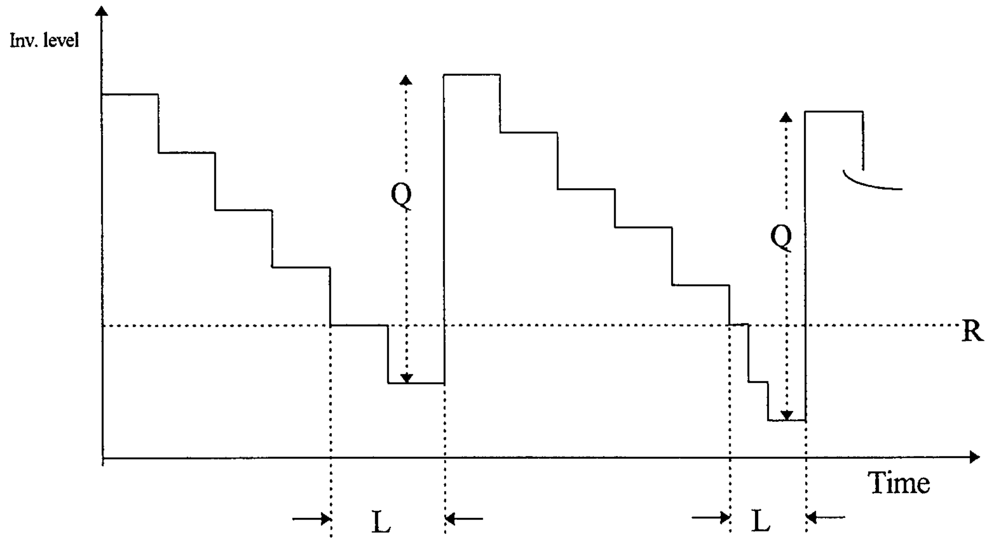
a. *Continuous Review Models*

The first continuous review model presented here is called the Q-system. It can be used for consumable items and allows for uncertain demand and procurement lead times. In addition, backorders are allowed and those demands associated with backorders will be filled as soon as stock becomes available from reorders placed by the inventory manager.

In this model inventory position (on hand plus on order minus backorders) is assumed monitored continuously using a transaction reporting system. This way the exact time to place an order (for more stock for the inventory) can be correctly determined. This exact time to reorder is identified by comparing the inventory position to a quantity called the reorder point, denoted R. Once the reorder point is determined the amount to order when an order is placed is called the reorder quantity, denoted Q.

In order to find the appropriate values for Q and R, a measure of effectiveness by which to judge the choice of values must be determined. Such a measure of effectiveness could for example be; total annual variable operating cost. In this case values of Q and R that would optimize the combination of annualized ordering, holding and backorder costs must be found/established.

Graphically, the reorder point and the changes in on hand inventory over time for a Q-system with variable demand and lead times can be depicted as shown in Figure 1. This figure shows net inventory (on hand - backorders) versus time:



R = reorder point (does not vary from order to order)
Q = replenishment quantity (does not vary from order to order)
L = lead-time (can vary from order to order

Figure 1. The Q-System

In the simplest approach to this model, the optimal order quantity Q^*, is that value which minimizes the ordering and holding cost. For a consumable item this results in:

$$Q^* = \sqrt{\frac{2SD}{IC}}\ , \qquad \textbf{(1)}$$

where:

$Q^* =$ Optimal order quantity,
$S =$ Order (Set - up) cost,
$D =$ Yearly demand,
$C =$ Item cost.

The reorder point (*R*) for a consumable is determined from minimizing the cost of carrying safety stock and of incurring backorders. It is a function of lead-time demand and the variability of demand.

The formula for R is:

$$R = (D \times L) + SS, \tag{2}$$

where:

$D =$ Average yearly demand,
$L =$ The procurement lead - time years,
$SS =$ Safety Stock, a function of demand and lead - time variability.

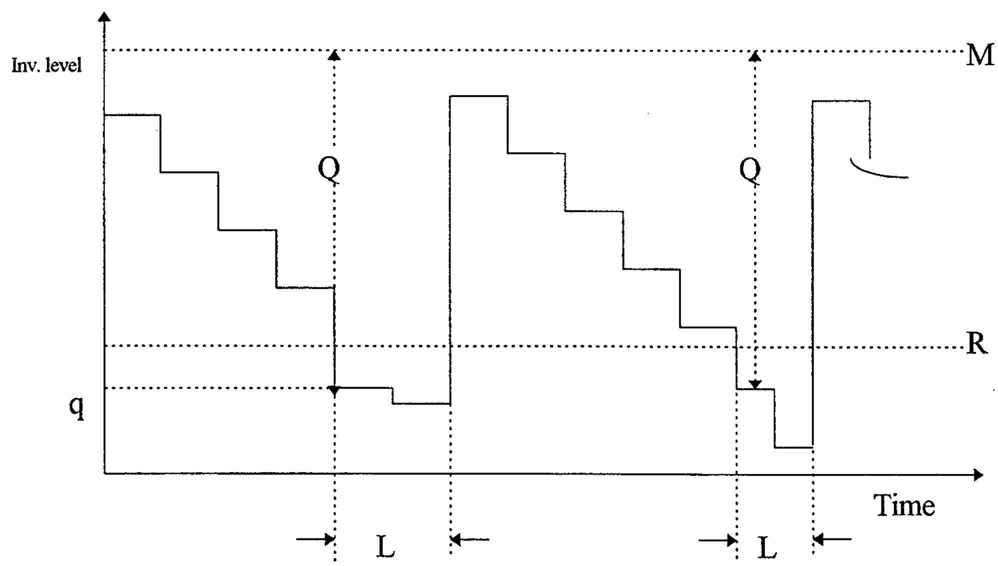
Another type of continuous review system is the min-max system. The decision variables used in the min-max system are the same as the decision variables used in the Q-system.

In the min-max system, a replenishment order is triggered when the on hand quantity reaches or falls below the reorder point R. This differs from the Q-system in that the Q-system places a replenishment order when the inventory position exactly reaches R. When customers can requisition material in quantities larger then one unit, its possible for the next demand (requisition) to take the inventory position below R instantaneously. The Q-system of control is not designed to deal with this, thus the min-max system is introduced. Under the min-max system, the replenishment quantity is increased (from Q) by the amount of the deficit between the reorder point quantity R and the inventory position at the time the order is placed.

Graphically, the reorder point and the changes in on hand inventory over time for a min-max system with variable demand and lead times can be depicted as shown in Figure 2. This figure shows net inventory (on hand - backorders) versus time:

b. Periodic Review Models

The periodic review system is based on a policy of reviewing and ordering at fixed regular intervals. One type of periodic review system is referred to as the P-system. In this control system, the inventory position is checked at the end of every T time units. If the inventory position is found to be below a level called the requisition objective (*RO*), then an order is placed which is large enough to bring the inventory position back up to the level of the *RO*. The actual quantity purchased can vary from order to order.



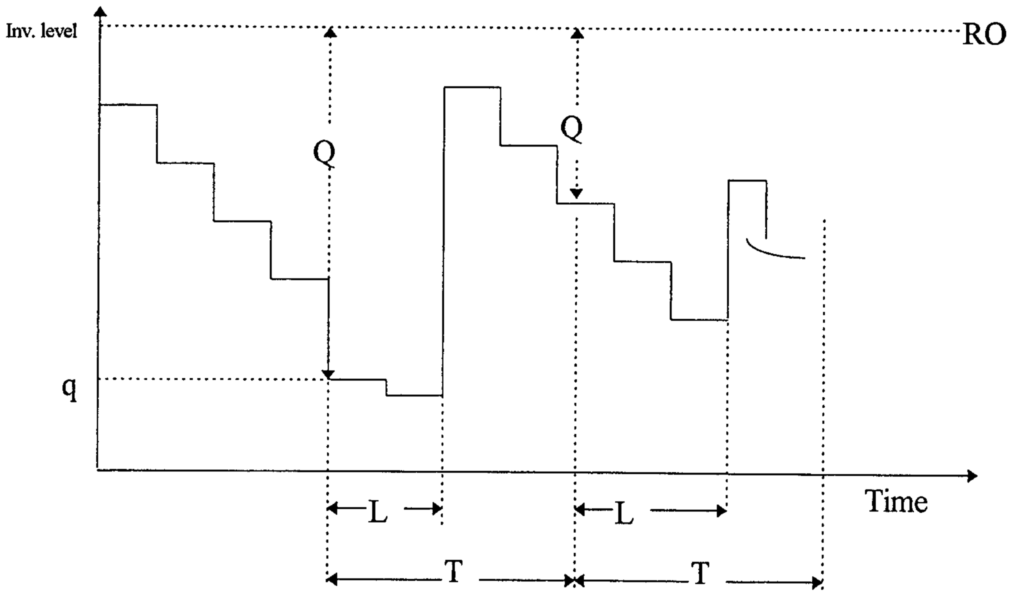
M = Maximum level
R = reorder point
M - q = replenishment quantity (Requisitions of all sizes allowed)
L = lead-time (random variable, i.e., can vary from order to order)

Figure 2. The Min-Max System

In the P-system, the two decision variables are the choice of value for *T*, the review interval, and for *RO*, the requisitioning objective. Because orders are placed at predetermined intervals without examining the stock position at times between orders, the value of *RO* should be set equal to expected demand between reorders, plus some allowance for demand variability.

Graphically, the P-system with variable demand and lead times can be depicted as shown in Figure 3. This figure shows net inventory (on hand - backorders) versus time:

The second type of periodic review system is actually a combination of the continuous min-max system and the P-system. This system is called the *T, R, RO* system. In this system the inventory level is reviewed every *T* units of time to see if the inventory position has dropped below the reorder point *R*. If so, a replenishment order is placed which will bring the inventory position up to the level of the requisitioning objective, *RO*. Under the *T, R, RO*



RO = Requisitioning objective
RO - *q* = Replenishment quantity (Requisitions of all sizes allowed)
T = Review Interval (Fixed Period)
L = Lead-time (random variable, i.e.,can vary from order to order)

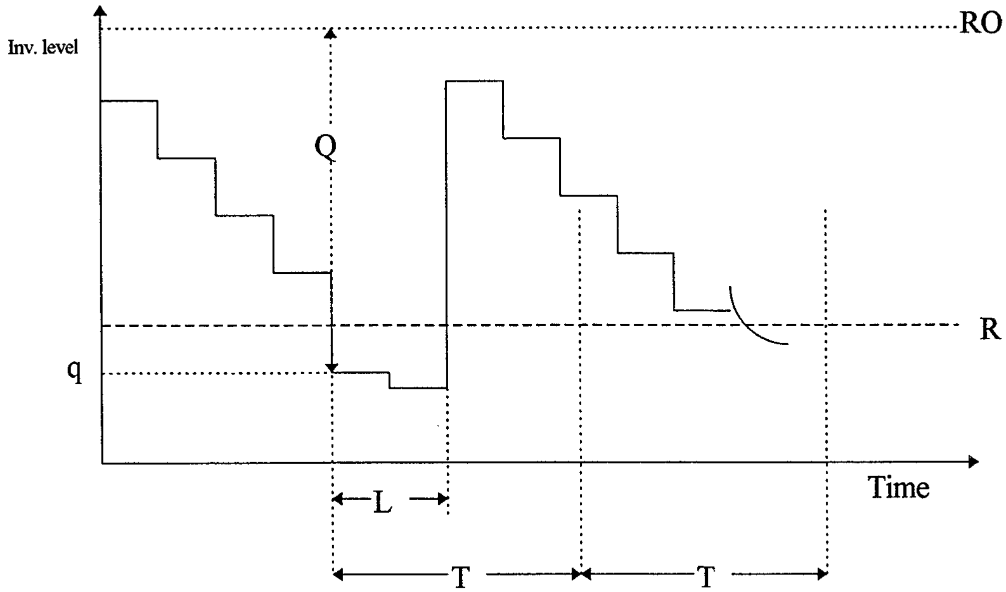
Figure 3. The P System

system there are three decision variables: the review interval, *T*; the reorder point, *R*; and the requisitioning objective, *RO*.

Graphically, the *T, R, RO* system with variable demand and lead times can be depicted as shown in Figure 4. This figure shows net inventory (on hand - backorders) versus time:

B. SAFETY STOCK AND REORDER POINT CALCULATIONS

If demand for an item is known and does not vary over time, then the demand is deterministic. And if in the same way all lead times in the replenishment process were deterministic, the right item would always be available when and where the customer needed the item. But this is not the case in real life, in real life demand vary all the time and if any thing is certain, it is that lead times will be different from replenishment to replenishment. Therefore, safety stock is held to protect against an extension of lead-time, the possibility that actual



RO = Requisitioning objective
RO - q = Replenishment quantity (Requisitions of all sizes allowed)
R = Reorder point
T = Review Interval (Fixed Period)
L = Lead-time (random variable, i.e., can vary from order to order)

Figure 4. The T,R,RO System

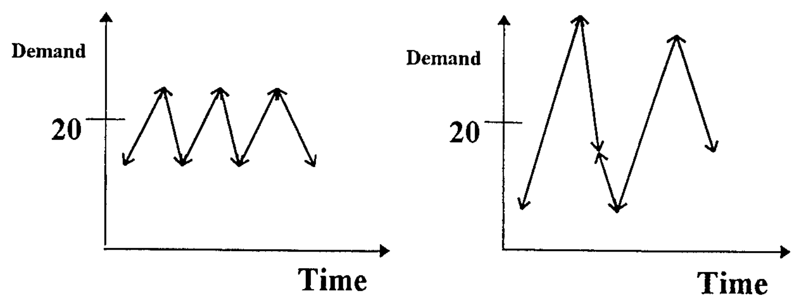
demand is greater than the forecast or both [Ref.4:p.48]. Does this mean that safety stock is only a good thing that help an organization serve their customers better. Not always, because if the items are delivered within specified lead-time and/or if demand for the item is less than the forecast, the safety stock is not only not needed, it is now in excess of requirements. Since holding safety stock means that, in some cases the organization will be able to meet demand only due to the safety stock, while in other cases the safety stock will mean excess inventory, the approach used to set safety stock is important.

1. Approaches to Setting Safety Stock

The simplest approach to setting a safety stock level is called the Equal Time Supply (ETS) [Ref. 16]. In this approach the safety stock is set in "time-unit" of stock, for example equal to 2 months demand. There is a problem inherent in this approach . Even if two items has

the same average demand, the variability of demand might vary greatly, and the Equal Time Supply approach will not account for the variance.

In Figure 5 the average demand for two items is the same, but the variance is different. The ETS method would generate the same safety stock for both items, and it is easy to see that service level would therefore be very different for the two items [Ref. 4] .



Demand A **Demand B**

Figure 5. Variance in Demand

What if the same service level is desired for all items? It is clear from Figure 5 that only relaying on average demand over a fixed time period is not the answer. If item B should have the same service level as item A, it would need more safety stock. A method that will account for the variance, which is the reason for having safety stock in the first place, is needed.

There is also other approaches to safety stock calculations. For example can safety stock calculation be based on the cost per stock-out event or per unit short. This might be a good approach in industries where cost of a shortage can easily be measured in form of premium transportation cost to deliver new items, set-up of overtime production and other costs involved in correcting the stock out [Ref. 16]. In the military, as one might expect it is found to be very difficult to measure the cost of a stock-out[1].

This is why the military, both in the US and in Norway, has based its safety stock calculation on a service goal. The service goal can for example be defined as the probability of

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1 Noted among other places in a note on the whole-sale inventory control system in the Norwegian Navy, obtained from Commander Senior Grade Tor Steinar Grindheim, Norwegian Navy Materiel Command, Logistics Division.

no stock-out per replenishment cycle. A company/organization might specify a service level of 95 percent, implying a probability of five percent that a demand cannot be met.

Higher safety stocks give higher service levels, but the actual service depends on the variation of lead-time demand. If demand varies widely, very high safety stock would be needed to ensure a high service level. In principle, widely varying demand would need an infinite safety stock to ensure a service level of 100 percent. Large stock can become prohibitively expensive, and therefore a lot of organizations usually settle for a figure around 95 percent [Ref. 4 p.151]. Often, items are given service levels related to their importance, so that very important items may have levels set at 98 percent, while less important ones are set around 85 percent [Ref. 4 p.151].

The basic equal safety level factor formula for safety stock (SS) is:

$$SS = k \times \sigma_L, \qquad \textbf{(3)}$$

where:

$k =$ The safety level factor,
$\sigma_L =$ Standard deviation of forecast errors
demand during a replenishment lead-time L

This formula implies that the lead-time is known and constant, which in most cases is not realistic. To deal with this problem, a formula for standard deviation of forecast errors where the lead-time vary along with demand has been developed [Ref.4]. Aggregated demand for an item is usually formed from a large number of smaller demands from individual customers. Therefore it is reasonable to assume that the resulting demand is continuous and normally distributed. So, if demand has a mean D and standard deviation σ_D and the lead-time has a mean L and standard deviation σ_L then lead-time demand has mean $L \times D$ (total demand in a "possibly" variable lead-time), and the standard deviation is:

$$\sqrt{L \times Var(D) + D^2 \times Var(L)}\,. \qquad \textbf{(4)}$$

If the lead-time happened to be known and constant, *Var (L)* would be equal to zero, and hence the standard deviation would be σ_L like in the first formula.

2. Reorder Point

As mentioned before the reorder point R is a point used to compare against the inventory position in order to know when one must place a new order. If we assume that both demand and lead-time varies, than the expected demand during the lead-time must be a factor of expected demand during a replenishment lead-time *E(D)* times the expected lead-time itself *E(L)*.

Let X be the total demand during the (possibly variable) lead-time, then:

$$E(X) = E(L)E(D) \; . \tag{5}$$

This gives following expression for reorder point R:

$$R = E(X) + SS \; . \tag{6}$$

Graphically this can be shown in the following way.

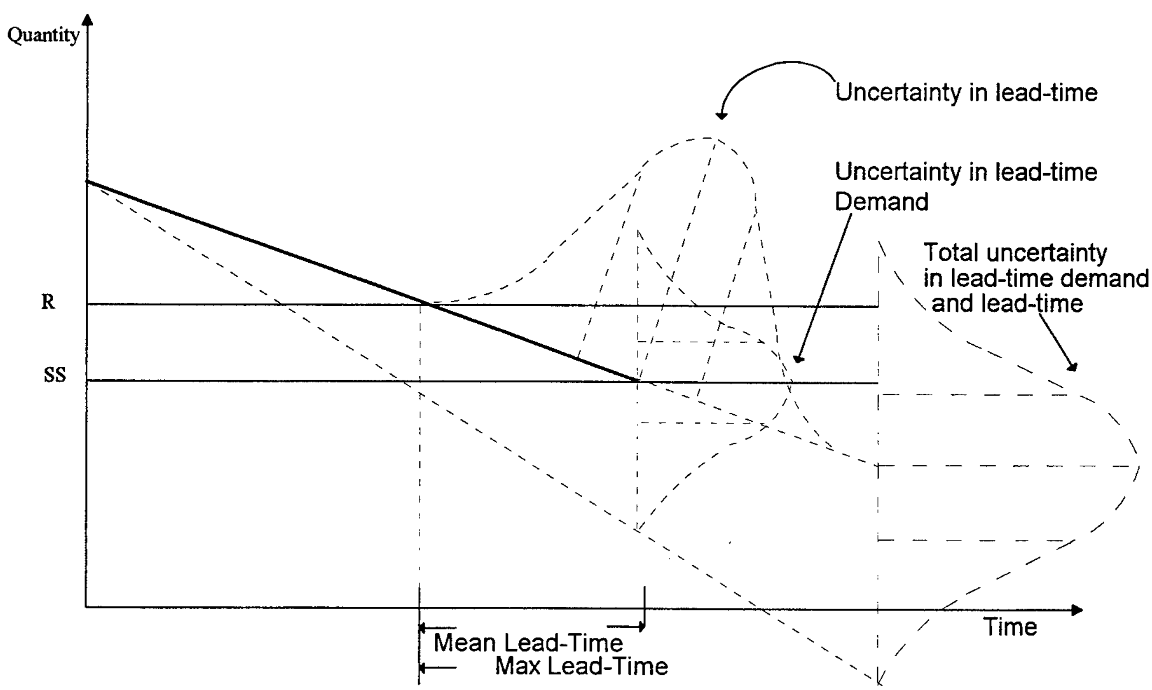

Figure 6. Total Variance in Lead-Time Demand and Lead-Time Itself

C. THE IMPACT OF LEAD TIMES

The cost of lead-time is not the lead-time itself but the impact it has on how much safety stock that must be carried due to variability in lead-time demand and the lead-time itself. The longer the expected lead-time is, the higher will the cost of holding the desired safety stock be.

How can this be? If demand in a period is higher than expected, this is fine as long the reorder point is not reached for the demanded item. The only thing that will happen is that the reorder point *R* is reached faster than expected (that means a steeper slope on the "inventory-reduction" curve) [Ref. 5].

Graphically this can be shown as follows:

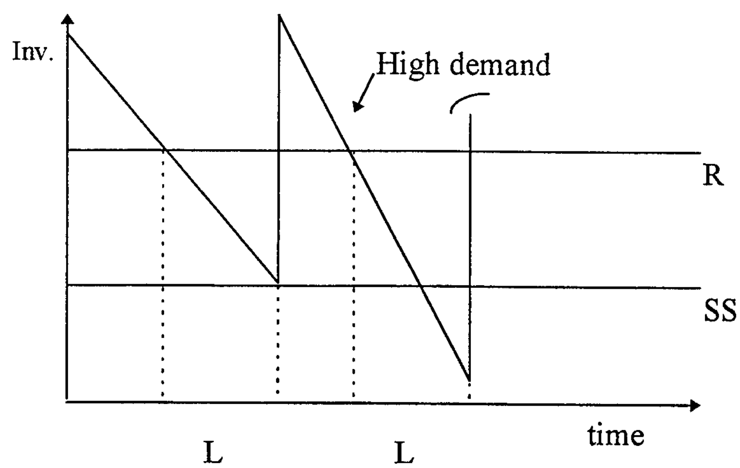

Figure 7. Variance in Lead-Time

The problem comes up as Figure 7 shows, if demand continuous to be higher than expected after the reorder point is passed. If the firm/organization, in this case had not had any safety stock, they would very soon run out of stock and not be able to meet demand.

As mentioned before, it is reasonable to assume that demand during lead-time in the case of consumables is continuous and normally distributed. With this as a starting point, an example of what a desired protection level of 95 percent. means for the need for safety stock is calculated in the following example.

Lead-time is assumed known and constant (this means that $\sqrt{L} = 1$). Monthly demand is normally distributed with $\mu = 15$ (quarterly 45) and variance $\sigma^2 = 10$.

This will give a safety stock need of:

$$SS = Z_{0.95} \times \sqrt{3 \times 10}.$$

Using the Standard Normal Curve Area Table to find the Z-value provides the following safety stock:

$$SS = 1.645 \times 5.47 \approx 9.$$

Say now that it is possible to reduce lead-time to one month, this would mean that the new safety stock would be:

$$SS = 1.645 \times 3.16 \approx 5 .$$

Assuming yearly holding cost rate of 23 % (US Navy holding cost for consumable items) and an item cost of $10,000, the total savings generated from the reduction in lead-time will in this case be:

$$(9-5) \times 10{,}000 \times 0.23 = \$9{,}200.$$

What will happen if lead-time vary along with demand. As stated before this is what is the case in the military. What will happen when instead of a fixed lead-time, the expected lead-time is three months $\{E(L) = 3\}$ with a variance of 1.21 $\{Var(L) = 1.21\}$, for then to be reduced to an expected lead-time of one month and hence a variance of 0.4.

Remember the formula for safety stock when both demand and lead-time is varying:

$$SS = Z_{0.95} \times \sqrt{L \times Var(D) + D^2 \times Var(L)}.$$

With 3 months expected lead-time and same expected demand as before this will give a safety stock of:

$$SS = 1.645 \times \sqrt{1 \times 10 + (3 \times 15)^2 \times 1.12} \approx 83.$$

By reducing the lead-time to 1 month the safety stock will be:

$$SS = 1.645 \times \sqrt{1 \times 10 + (15)^2 \times 0.4} \approx 17\,.$$

Assuming yearly holding cost rate of 23 % and item cost of \$ 10,000, the total savings generated from the reduction in lead-time will in this case be:

$$(83 - 17) \times 10{,}000 \times 0.23 = \$151{,}800\,.$$

Compared to the case where only variation in demand where protected against, the saving is \$ 142,600 larger.

D. SUMMARY

In this chapter, two basic inventory control models, the continuous model and the periodic model was introduced and explained.

Further this chapter has shown that the longer the lead-time the higher is the uncertainty in both demand and lead-time itself. Given any service level, the higher the uncertainty, the higher must the safety stock be. High safety stock means high holding cost. It was also found that the savings by reducing lead times gets larger when lead-time varies along with demand. In other words time is definitely money in the case of lead times.

III. INVENTORY CONTROL AND REPLENISHMENT AT THE ROYAL NORWEGIAN NAVY MATERIEL COMMAND

A. INTRODUCTION

In this chapter the Norwegian Navy Materiel Command's inventory control model will be described and compared to the theoretical models described in last chapter. In order to better understand the redesign efforts that later in this thesis will be conducted on current replenishment process, a brief introduction to the Norwegian Navy, and Navy Materiel Command will also be given.

B. THE ROYAL NORWEGIAN NAVY

This section will give a very brief introduction to the Norwegian Navy, and is based on the Norwegian Ministry of Defense's publication; "Norwegian Defense Facts and Figures 1997" [Ref. 14].

Because Norway is a country with a small population, spread over a large area, all sectors of the community are under an obligation to render assistance to the defense of Norway. This requires close cooperation between civilian and military authorities within a total defense concept.

A number of tasks which in other countries are the responsibility of the armed forces are in Norway handled by civilian institutions. This applies especially to logistics support and transportation. In the event of war the Armed Forces can requisition civilian aircraft, ships, motor vehicles and other needed goods and services.

Mobilization of the Norwegian general public is of major importance to the total defense of the nation. The complete picture of the Navy's defense capability is therefore better than what the peacetime force personnel numbers might indicate.

The Navy has a peacetime force of approximately 9,000 officers and conscripts. After an eventual mobilization, the Navy force will increase to approximately 25,000.

The Royal Norwegian Navy consists of the Navy, the Coast Guard and the Coastal Artillery. Naval vessels participate in all main tasks of the Navy, both in peacetime, crisis and war. The main task of the Coastal Artillery is to block fjords leading to strategic towns and harbors. This is the reason why Coastal Artillery forts are placed at the mouths of such fjords. In addition, the Coastal Artillery is an important element in the defense of areas important or crucial to our general defense capability. The Coastal Artillery will also provide support for Army operations if possible.

The Commanders of the Armed Forces Southern Norway and Northern Norway exercise the operative command of the vessels of the Navy, the Coastal Artillery forts and the Coast Guard vessels in their respective areas.

C. THE NORWEGIAN NAVY MATERIEL COMMAND

In this section the Norwegian Navy Materiel Command's organization and tasks will be described briefly. The description is based on The Materiel Command's Directive Number 43 (SFK Direktiv Nr. 43) [Ref. 19].

The Materiel Command's main task is to produce current and future materiel readiness for the Navy. To obtain this very broad goal the Materiel Command is today divided into four different divisions which each has their own Commanding Officer (CO) (or equivalent civilian title for the Maintenance Division) and an Executive Commanding Officer and Staff Section on top of the divisions.

The organizational table (Figure 8) gives a broad picture of how the Materiel Command is organized.

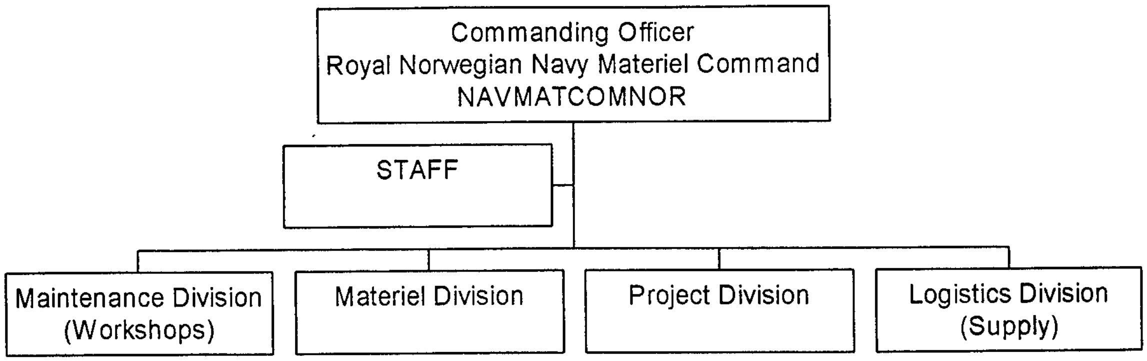

Figure 8. Royal Norwegian Navy Materiel Command

1. Staff

The Materiel Command's Staff is the CEO's primary service and support tool. The Staff will in cooperation with the different divisions help the CEO gain the best possible knowledge and give support so that right decisions can be made in order to reach the main goal of maximum current and future materiel readiness. The Staff shall also work as a common support section for all divisions within the Materiel Command.

2. Maintenance Division

As the title indicates the main task for the Maintenance Division is to perform needed maintenance on a large part of the Navy's equipment. The Maintenance Division has also a senior responsibility over several Naval maintenance facilities throughout Norway. This division is also responsible for procurement, storage and maintenance of all of its own equipment . In cooperation with the other division the main goal for the division is to maximize operational availability within given budgetary limits.

3. Materiel Division

The Materiel Division is responsible for all technological studies, and assessments of existing equipment. The division do also have the overall responsibility for which technological solutions are chosen for new equipment in cooperation with the Project Division. Another important area for the Materiel Division is the use, and infrastructure of information technology within the Materiel Command. The division shall aid all other divisions in questions and work concerning technology, especially new technology. It is also within the tasks of the division to

coordinate the Materiel Command's combined effort to run and maintain the Navy's materiel and systems.

4. Project Division

The Project Division has the administrative responsibility for all materiel projects in the Navy. The division coordinates needed effort/inputs from other divisions and from the rest of the Navy and outside organizations. It is the Project Division that has the main responsibility for planning, executing and terminating projects in accordance with rules, regulations and goals given by senior authorities.

5. Logistics Division

The Logistics Division is responsible for storage and replenishment of inventory items for the Fleet and Coastal Artillery in most of Norway. The division has authority in all questions concerning supply and storage of spare parts and consumables for the Norwegian Navy . The main goal for the division is to gain maximum materiel readiness in form of operational availability within given budget.

D. THE MATERIEL COMMAND'S INVENTORY CONTROL POLICY

Description of the Materiel Command's inventory control policy and models given in this section, is partly based upon a Norwegian Navy Materiel Command Memorandum describing the inventory model [Ref. 10].

The Norwegian Navy has used computer-based inventory control systems since around 1970. The model that still is in use today, was developed throughout the early seventies in cooperation with the University of Bergen. The model is based on IBM's IMPACT (Inventory Management Program and Control Techniques) model. As mentioned in Chapter II, the main purpose of the Norwegian Navy's inventory control policy is to find the optimal combination of storing cost, the ordering cost, and the stock-out cost. However, the Norwegian Navy has never been able to quantify the cost of a stock-out in a manner that would satisfy an inventory control policy based on balancing the three mentioned cost factors. The problem has therefore been simplified to deciding a optimum order quantity (Q), reorder point (R) and safety stock

(*SS*) given a acceptable level of risk of stock-out. The current main policy in the Norwegian Navy is that the order quantity shall cover one quarter of normal use (demand), and that the desired protection level equals 95 percent (acceptable level of risk is thus five percent). An order quantity based on one quarter of demand might however not be optimal at all, as shown later. So already at this stage the policy conflict somewhat with its own goal.

1. Inventory Control Models

The Norwegian Navy's inventory control program divides inventory items into three main handling categories.

The first category (called the A-model) is controlled manually by Materiel Command personnel. The item managers will set "maximum quantity on hand" and reorder points manually. This means that demand from "customers" will not automatically change any of the figures for the different items placed under this category. This model is used on items that have very low demand, are part of an almost unused war-reserve or are for other reasons are found not suited for automated control.

The second category (B-model) is partly controlled by the computer system and partly by the item manager. This model is used on items that have too little demand to give a good base for forecasting, or for new items just introduced into the inventory system. A new item is defined as an item that the Navy has little or no historic data to use for forecasting purposes. Theoretically the same principles that will be described for the C-model is also working in the B-model. The main exception is that maximum inventory quantity (*M*), and reorder point (*R*) is not automatically adjusted by the computer system as in the C-model.

The third category (C-model), is the way the Navy originally intended as the principal means of control for all items. This model is basically what is described in Chapter II as the min-max version of a continuous review model. In this model the computer system automatically decides maximum inventory quantity (*M*), reorder point (*R*) and safety stock (*SS*) based on programmed input data. Examples of requirements that the items must fulfill to be in this category are:

- The item has been in the inventory system for at least six months.

- Demand over the last 12 months equals or is grater then 10 units.
- Demand forecast for next period is equal to or greater than three units.

The different control quantities (that is Q,, R and SS) are adjusted each month based on the calculated difference between the period's real demand and the forecasted demand (more on the Norwegian Navy's forecasting in Sub-Section 3).

2. Lead-time Calculations

Total lead-time (L) in the replenishment process is defined by the Navy as the time elapsed from a need for an item occurs until that need is satisfied. In reality this definition is rewritten to be interpreted as the time elapsed from an item reaching its reorder point R until the item is delivered or made ready for issue in the supply system.

As mentioned before, lead-time is a combination of two parts. The first part is the vendor's time to deliver an order. The second part is called administrative lead-time. According to Norwegian officials the administrative lead-time very often can be as long or longer than the vendor's delivery time.

The lead-time forecast for the individual item is derived as a running average of the two latest replenishment lead times of the item in question. If no statistic is known on an item, the average lead-time for the item's NATO-stock number class will be used. During this research it could not be found whether the time since last replenishment had any significance on the decision of using the average of the two latest replenishments.

3. Forecasting

As mentioned before the Norwegian Navy has a main policy of order quantity covering one quarter demand for the individual item. A forecasting technique must therefore be built inside the inventory control model.

For the C-model explained here, the Navy uses exponential smoothing. Exponential smoothing is a forecasting method that is easy to use and is handled efficiently by computers [Ref. 15]. It involves little record keeping of past data. The forecast is calculated by using last

period's forecast and adding a part of last period's forecasting error. The basic exponential smoothing formula used by the Norwegian Navy can be shown as follows:

$$\textit{New forecast} = \textit{last periods forecast} + (\textit{last periods actual demand} - \textit{last periods forecast}). \quad \textbf{(7)}$$

Alpha (α) is a weight (or smoothing constant), and it has a value between 0 and 1, inclusive. The Norwegian Navy uses a smoothing constant of 0.2

Mathematically this can be written as follows:

$$F_t = F_{t-1} + \alpha\left(A_{t-1} - F_{t-1}\right), \quad \textbf{(8)}$$

where:

F_t = new forecast,
F_{t-1} = previous forecast,
α = smoothing constant,
A_{t-1} = previous periods actual demand.

The Navy system calculates a new forecast each month, and this means that order quantity (Q) will equal 3 times the forecast (forecasted quarterly demand).

4. Forecasting Errors

The computer system will in addition to the forecasting quantity, calculate an average forecasting error, later used in the safety stock calculation. This measure of the overall forecast error for the model is called the mean absolute deviation (*MAD*). The general formula for *MAD* can be written as:

$$MAD = \frac{\sum |\text{forecast errors}|}{n}. \quad \textbf{(9)}$$

As one can see, this is the sum of the absolute values of the individual forecast errors, divided by the number of periods of data (n). It can also be mentioned, that by analyzing different smoothing constant, in the forecasting process, the smoothing constant that gives the lowest *MAD* will be preferred (as mentioned before it is 0.2 in the Norwegian Navy today).

The mean absolute deviation for the Navy's one month forecasting period, is based on exponential smoothing formula, and can be expressed mathematically as follows:

$$MAD_N = MAD_O + \alpha\left(\left|A_{t-1} - F_{t-1}\right| - MAD_O\right), \qquad \textbf{(10)}$$

MAD_N = New MAD,
MAD_O = Old MAD.

Equation 10 gives a forecasting error for the forecasting period. In order to calculate safety stock, as pointed out in Chapter II, standard deviation of forecast errors for demand during the replenishment lead-time is needed. The MAD works here as an approximation of standard deviation.

Expected forecasting error for the replenishment lead-time has the following formula:

$$MAD_L = MAD_N \times \left(\frac{L}{FI}\right)^{\beta}, \qquad \textbf{(11)}$$

where:

FI = Forecasting interval (1month),
β = Smoothing constant (beta) used to smooth the forecasting error when the lead - time is longer than the forecasting period (0.7 in the Norwegian Navy).

5. Safety Stock Calculation

As explained in Chapter II, Section B, Sub-Section 1, a formula for standard deviation of forecast errors where lead-time varies along with demand has been developed [Ref. 4]. In the Norwegian Navy's version of safety stock calculation, it is clear that the Navy does not really incorporate the variation in lead-time in the same way as this formula does. It is only the mean lead-time that is forecasted, and not the variation. The Navy does however incorporate the forecasted replenishment lead-time demand mean absolute deviation, but this does not give any protection against variation in lead-time as the formula mentioned above does. No data was obtained in the research for this thesis on how many times the Navy has had stock-outs due to variation in lead-time, so it is hard to say what the effect is in real life.

The safety stock calculation in the computer system is a two step process. The first step is to calculate a so called service function (SEFU). The formula for SEFU looks like:

$$SEFU = Q/_{MAD_L} \times (1-k), \tag{12}$$

where:

$Q =$ order quantity (3 monthly demand),
$k =$ safety level factor,
$MAD_L =$ forecasting error for lead - time.

The second step is to calculate a safety-factor (SAFA). SAFA estimates how many MAD_L is needed to get the desired service level (95 %). The formula for SAFA can be expressed as follows:

$$SAFA = -0.46 \times \text{In}(SAFU + 0.0001) + 0.54 - 2.3 \times (SEFU) + 1.8 \times (SEFU)^2 - 0.34 \times (SEFU)^3 . \tag{13}$$

The relationship between SEFU and SAFA is a continuum from if SEFU = 0, than SAFA = 3 to if SEFU = 0.58 than SAFA = 0.

Finally the formula for Safety Stock (SS) can be expressed like:

$$SS = SAFA \times MAD_L . \tag{14}$$

6. Reorder Point

The system uses the monthly new forecast (F_t) for each item, times forecasted replenishment lead-time plus the already decided safety stock (SS) to decide the reorder point for the individual item.

Mathematically this can be expressed as follow:

$$R = \left(F_t \times L/_{4.3}\right) + SS, \tag{15}$$

$R =$ reorder point,
$L =$ lead times in weeks.

E. POSSIBLE SAFETY STOCK SAVINGS DUE TO REDUCED LEAD-TIME

In this section the mathematical example started in Section C of Chapter II will be continued. Due to the fact that the Norwegian Navy does not use economic order quantity, but a fixed order quantity based on the next month's forecasted demand times three, and does not protect against variation in lead-time, the possible savings in safety stock from a reduction in administrative lead-time will in many cases be lower than in the theoretical model. Some might therefore say that the Norwegian Navy's way of calculating safety stock is fairly good, since it does not create a very large safety stock in the first place. The problem however is the effect a fixed order quantity based on a quarter of forecasted demand have on average holding and ordering cost, and the possible reduced protection against stock-out.

Remember from Chapter II, Section C, the example used an item with a monthly demand normally distributed with a mean of 15 and a variance of 10. Mean lead-time of three months was assumed.

Continuing this example fitted into the Norwegian Navy's model, new forecast (F_t) is assumed to be 15 and hence Q = 45 (three times new forecast).

In statistical research it is found that standard deviation can be approximated by multiplying MAD with a factor of 1.25 $(\sigma = 1.25 \times MAD)$ [Ref.3 P. 4-A-12].

Knowing that the standard deviation of monthly demand in this example was equal to the square route of ten $(\sigma = \sqrt{10})$, MAD can be approximated in the following way:

$$MAD = \frac{\sqrt{10}}{1.25} = 2.5298 .$$

This MAD is then used to approximate the expected forecasting error for the replenishment lead-time, which was 3 months.

$$MAD_L = 2.5298 \times \left(\frac{3}{1}\right)^{0.7} \approx 5.4585 .$$

The next step will be to calculate the service function (SEFU)

$$SEFU = \frac{45 \times (1 - 0.95)}{5.4585} \approx 0.4122 .$$

How many MAD_L is now needed to get the desired safety level of 95 percent? This is done through the calculation of the safety factor (SAFA):

$$SAFA = -0.46 \ln(0.4122 + 0.0001) + 0.54 - 0.23(0.4122) + 1.8(0.4122)^2 - 0.34(0.4122)^3 \approx 1.134779$$

Finally safety stock level needed to achieve a 95 percent safety level can be decided.

$$SS = 1.134779 \times 5.4585 = 6.194 \approx 7 .$$

Assume that reengineering of the replenishment process has reduced the mean lead-time from three to one month. What effect will this have on the automated calculation of safety stock need in the Norwegian Navy's inventory control model?

The order quantity Q, is still 45 (demand has not changed). The mean absolute deviation (MAD) for the forecasting period (one month) will also remained unchanged from the reengineering:

$$MAD = 2.5298 .$$

Since the lead-time is reduced, MAD_L will however be changed:

$$MAD_L = 2.5298 \times \left(\frac{1}{1}\right)^{0.7} = 2.5298 .$$

The new service function (SEFU) will be as follows:

$$SEFU = \frac{45 \times (1 - 0.95)}{2.5298} = 0.8893 .$$

The relationship between SEFU and SAFA states that a SEFU larger than 0.58, will give a safety factor (SAFA) equal to zero. This means that the safety stock calculation will give:

$$SS = 0 \times 2.5298 = 0 .$$

In other words safety stock is no longer needed to give the desired safety protection level of 95 percent.

As in Chapter II, Section C, a unit cost of \$10,000 and a holding cost rate of 23 percent is used. The total savings generated from the reduction in lead-time will be:

$$(7-0)\times 10{,}000\times 0.23 = \$16{,}100.$$

This is more than with the fixed and known lead-time example in Chapter II (\$9,200), but less than the varying demand and lead-time example (\$151,800). Why is this the case?

The Norwegian Navy's model does not include protection against variance in lead-time. This fact will give a lower safety stock calculation, but also a theoretically lower protection against stock-out. The model does also include a smoothing constant (Beta of 0.7) on the mean absolute deviation of forecasting errors, which means a lower safety stock for all lead times, than what would have been experienced with the theory model.

Savings were found to be larger than in the theory model where lead-time is known and constant. This is partly due to the fact that the Norwegian model uses a safety-factor calculation with a "cut-off point". The "cut-off point" basically says that if the absolute deviation of forecasting errors is small enough, the safety-factor shall be zero, and hence the safety stock need will be zero. The theory model does not have any form of "cut-off point", and some form of safety stock no matter how small the standard deviation of forecasting errors becomes will be experienced.

It seems clear that the Norwegian Navy's model will give a poorer protection against variance during the lead-time, since it only protects against variance in demand and not against variance in lead-time itself. The cost will naturally be lower though because as shown in Chapter II, time or rather the variance in time is costly to protect against.

It is not within the scope of this thesis to research what effect the apparent neglect of variance in lead-time has meant on the amount of stock-outs that has occurred during the years the Materiel Command has used this model. But such a study should definitely be conducted if it is found that it has been a problem to keep the desired protection level of 95 percent.

Another possible problem that this study of the Materiel Command's model has made clearer, is the calculation of order quantity, and its associated costs. When safety stock was

calculated in the examples in Chapter II, the assumption of economic order quantity (Q^*) was part of how the formulas were built.

In the Norwegian Navy's model, this is not the case. This model decides order quantity based on three times the new forecasted monthly demand (which does not necessarily even be close to Q^*).

The example used above is continued by assuming an ordering cost for the item of \$200. With this ordering cost the economic order quantity (Q^*) is:

$$Q^* = \sqrt{\frac{8 \cdot 45 \cdot 200}{0.23 \cdot 10000}} = 5.59 \approx 6.$$

The Norwegian Navy's policy says three times monthly forecast, or an order quantity (Q) of:

$$Q = (3 \cdot 15) = 45.$$

Will the average holding cost be higher when economic order quantity is not used? Yes, but not necessarily clear cut. Knowing that the formula for average holding and ordering cost (AHO) looks as follows:

$$AHO = \frac{Q}{2} \cdot (C \cdot P) + \frac{D}{Q} \cdot S, \qquad \textbf{(16)}$$

where:

$Q =$ order quantity,
$C =$ holding cost (as percentage of unit price),
$P =$ unit price,
$D =$ yearly demand,
$S =$ set - up (or ordering cost).

Given reduced lead-time from three to one month, the average holding and ordering cost plus holding cost of safety stock of the Norwegian Navy's model and the theoretical model respectively will be (assuming ordering cost of \$200):

Norwegian Navy:

$$AHO = \frac{45}{2}(0.23 \cdot 10000) + \frac{180}{45} \cdot 200 = \$52,550$$

The Navy has no safety stock, therefore the total is $52,550

Theoretical model:

$$AHO = \frac{6}{2}(0.23 \cdot 10000) + \frac{180}{6} \cdot 200 = \$12,900$$

$$SS = 17(10,000)0.23 = \$39,100$$

The total for the theoretical model is $52,000

The difference in this example is only marginal. Even if this is only an example, it shows that the solution not necessarily is a clean cut. It is very important to notice that if the variance in lead-time demand and/or lead-time itself was smaller the Norwegian Navy's model would have a much higher inventory cost than the theory model due to a lower safety stock need in the theory model.

By reengineering the replenishment process and reducing lead-time, one automatically reduces safety stock need and hence the cost of holding safety stock. It can also be assumed that the cost of ordering items for replenishment, when introducing new and more effective approaches like consolidation of excising procurement processes or the introduction of electronic commerce, will reduce the ordering cost.

The example shown on average holding and ordering cost, shows that the Norwegian Navy very closely should look at the possibility of using some form of economic order quantity calculation instead of always procuring a fixed one quarter's forecasted demand. This is however beyond the scope of this thesis and clearly means that the inventory control model will have to be closely evaluated and possibly changed. The savings will not come "automatically" because of a process change as with reducing administrative lead-time, but the savings potential might be very large indeed.

F. SUMMARY AND COMMENTS

In this chapter the Norwegian Navy Materiel Command's inventory control policy has been described and compared to the basic inventory models presented in Chapter II.

In Section C, Sub-Section 1, it was found that the fully automated inventory control model (called the C-model), originally was intended as the principal mean of control for all items stored at the Materiel Command. To find whether this is the situation currently experienced at the Command, an inquiry into the Materiel Command's database was conducted on behalf of this research by the Command's Logistics Division. The research was done by using a database browser that collected needed data from the Command's inventory database (An example of the output is included as Appendix E). The research revealed that out of a total of 135,000 different stock keeping units (different NATO-numbers), about 32,000 were controlled by the A-model, about 98,800 were B-model units and only 4159 items were listed as controlled by the fully automated C-model.

This means that the automated model, originally intended as principal mean of control, today has no more than about three percent of the different line items represented at the Materiel Command.

Even though it is not within the scope of this thesis to evaluate the "goodness" of existing inventory control model, this finding strongly support what was mentioned in Chapter II, Section A, namely that: "The military's goal of maximizing operational readiness may be at odds with the classic inventory management goals of minimizing costs." This can be said because the A and B-model does not, as strongly as the C-model, follow the classic inventory goal of minimizing cost, but is more or less manually managed by the individual item manager. An item manager who's main incentive in most cases is to not be out of stock, and not necessarily to obtain this in the most economical way. This made perfect sense in a world of generous budgets, since operational readiness is far more important than a nonexistent bottom line. However, as mentioned in Chapter I, budgets are no longer generous and reduction in logistical spending has now become very important.

The realization of the C-model only consisting of about three percent of the items, together with the finding that the Navy's model does not protect against variation in lead-time has reduced the initially assumed potential of automatically large savings in holding cost of safety stock. This does not mean however that savings from reduction in administrative lead-time is nonexistent.

As mentioned above, the Materiel Command's control model does not protect against variation in lead-time. And even though this research gave no verified data on how many times the Navy has had stock-outs due to variation in lead time, or if the item managers buy more than the model suggest to protect themselves against variability, gathered data indicates that this happens. The data gathered from the inventory database, (see Appendix F) strongly suggest that this is the case. Even if only a small part of total inventory is controlled be the automated model, and hence a reduced savings potential on automatically generated safety stock is found, a reduction in lead-time will reduce variability. Reduced variability will reduce the possibility of stock outs due to variability in lead time, and even more important hopefully increase trust in system proposed (computer calculated) replenishment quantities, thus reduce excessive inventory. These benefits, especially for the A-model and B-model, are harder to quantify than savings in holding cost of automatically generated safety stock in the C-model, but they will be there whether they are measured or not.

IV. BUSINESS PROCESS REENGINEERING

A. INTRODUCTION

Business Process Reengineering (BPR) can be defined as fundamental rethinking and redesign of business process to achieve dramatic improvements in critical contemporary measures of performance such as cost, quality, service and speed [Ref. 6 P.13].

This might seem like a very "dramatic" definition of the term BPR, but what is a business process really? The following explanation is largely based on an article by Jeff Hiatt [Ref.7].

> If you have ever waited in line at a grocery store, bank or a fast food restaurant, you can appreciate the need for process improvement. In these cases, the "process" is called the check-out process, and the purpose of the process is to pay for and get your goods or services. The process begins with you stepping into line, and ends with you receiving your goods and your receipt and leaving the place. You are the customer (you have the money and you have come to buy the goods or service), and the store, bank and restaurant are the suppliers. The process steps are the activities that you and the suppliers personnel do to complete the transaction.

This is one example of a business process. Another example of a "business process" can be the replenishment of items to a military wholesale level supply system. There is an input in form of the inventory control system reaching its reorder point and generating a replenishment proposal. A transformation of the proposal to make a buying decision, place an order with a vendor and so on, before the final output appear in form of new items ready for issuing in the supply system. In this way the business process is simply a set of activities that transform a set of inputs into a set of outputs (goods or services) for another person, organization or process, using people and tools [Ref. 7].

So why business process improvement? Improving business processes is paramount for private businesses to stay competitive in today's marketplace. Over the last 10 to 15 years companies have been forced to improve their business processes because customers are demanding better and better products and services. And if they do not receive what they want

from one supplier, they have many others to choose from (hence the competitive issue for businesses). This is not exactly the case for the military. The fact is that our customers (the fleet) require the same operational availability as before, and hence the same or better service in form of availability of spare parts and other goods and services. Availability of inventory items must be obtained by the logistics division with far less money than before (shrinking budgets). To be able to meet "customer" demand it is paramount for military logisticians to look closely at their "business processes".

B. CONTINUOUS IMPROVEMENT MODEL

Many companies began business process improvement with a continuous improvement model. This model attempts to understand and measure the current process, and make performance improvements accordingly [Ref. 7].

Figure 9 illustrates the basic steps. One start by documenting what today's process is, establish some way to measure the process based on what customers want, do the process, measure the results, and then identify improvement opportunities based on the data collected. Process improvements are then implemented, and the performance of the new process is measured. This loop is repeated over and over again, and is therefore called continuous process improvement. It may also be called business process improvement or functional process improvement.

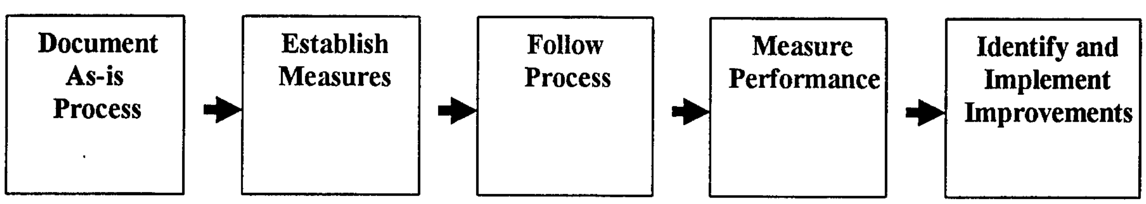

Figure 9. Continuous Improvement Model

This method for improving business processes is effective to obtain gradual, incremental improvement. It also foster the need for continuous work with the current process, and preferably in a quantifiably (scientific) way, by someone in the organization [Ref. 7]. Because many processes in organizations were not developed with the aid of

scientific/quantifiable tools and methods traditionally found within operational research, it might be very hard to continuously work with this processes in a quantifiably way.

C. BUSINESS PROCESS REENGINEERING

According to Hiatt [Ref.7], over the last 10 years several factors have accelerated the need to improve business processes. The most obvious is technology. New technologies (for example electronic commerce and the Internet) are rapidly bringing new capabilities to businesses, thereby raising the competitive bar and the need to improve business processes dramatically.

As a result, companies have sought out methods for faster business process improvement. Moreover, companies want breakthrough performance changes, not just incremental changes, and they want it fast. Because the rate of change has increased for everyone, few businesses can afford a slow change process. One approach for rapid change and dramatic improvement that has emerged is Business Process Reengineering (BPR).

BPR relies on a different school of thought than continuous process improvement. In the extreme, reengineering assumes the current process is irrelevant - it does not work, it is broke, forget it. Start over. Such a clean slate perspective enables the designers of business processes to disassociate themselves from today's process, and focus on a new process. In a manner of speaking, it is like projecting into the future and asking: what should the process look like? What do the customers want it to look like? What do other employees want it to look like? How do best-in-class companies do it? What can be done with new technology?

Such an approach is shown in Figure 10. It begins with defining the scope and objectives of the reengineering project, then going through a learning process (with customers, employees, competitors and non-competitors, and with new technology). Given this knowledge base, a vision for the future can be created and new business processes designed. From analysis/description of current processes a plan of action based on the gap between current processes, technologies and structures, and "to be" process can be created. Then it is a matter of implementing the solution.

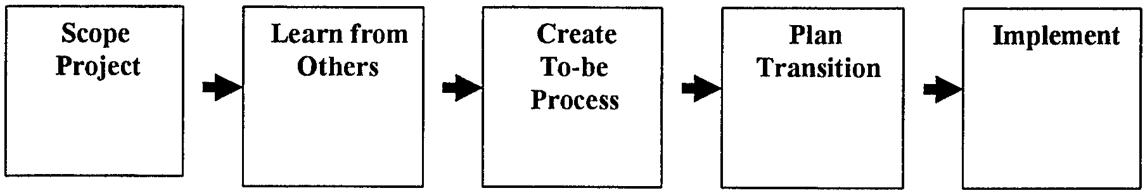

Figure 10. Business Process Reengineering Model

In summary, the extreme contrast between continuous process improvement and business process reengineering lies in where one start (with today's process, or with a clean slate), and with the magnitude and rate of resulting changes.

D. PROCESS REDESIGN AND ENGINEERING

The last approach to designing and redesigning of a process that will be describe in this thesis is called; Process Redesign. This approach was chosen to be used in the redesign of the Royal Norwegian Navy Materiel Command replenishment of inventory items. What is the difference between this approach and the traditional business process reengineering approach? Hansen [Ref. 8] says:

> Engineering is the application of scientific and mathematical principles to practical ends such as the design, construction and operation of efficient systems. These principles must also be applied to process reengineering. Unfortunately, most BPR approaches, although claiming to represent radical change, are no more than the continuation of the evolution that has led to the processes that exist today. Such approaches to BPR emphasize increasing communications about processes. The only difference in the many BPR approaches being popularized are the differences in their approach to increasing communications. Whereas communications may be important, talking about business processes is only part of the BPR effort. Before a business considers reengineering any process, it should first consider engineering the process. Process engineering is the application of engineering disciplines to the analysis and improvement of processes. Although a process cannot be reengineered if it has never been engineered, a process can be engineered and reengineered at the same time by applying process engineering methods. The application of scientific methods to business process reengineering is a radical, revolutionary departure from comfortable, philosophical process reengineering approaches we continue to hear about.

Hansen does not call his approach Process Redesign, but other researchers using the same approach give the technique its name. Davenport and Short have written a paper called Information Technology and Business Process Redesign [Ref.8 P.101], where they more or less express they same thoughts as Hansen on the importance of using scientific/engineering methods and not only "talk" to reach a vision or objective. In their paper, Davenport and Short have identified five steps in process redesign.

These five steps have been somewhat modified to fit this thesis. With the modification the Process Redesign approach can be pictured in Figure 11:

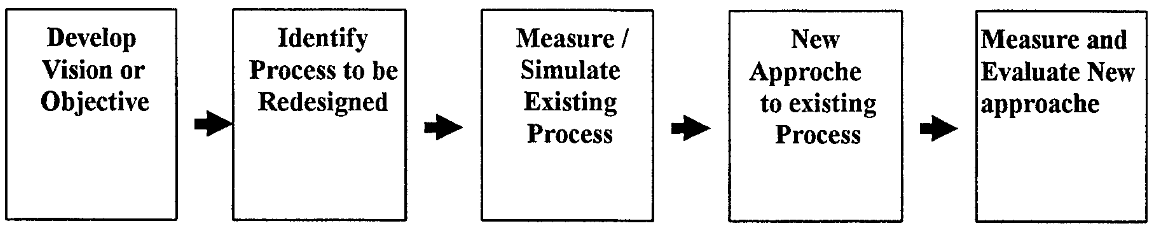

Figure 11. Business Process Redesign Model

As described in Chapter I, the objective of the process redesign in this thesis, is to reduce administrative lead-time in the replenishment of inventory items to the Norwegian Navy's wholesale level supply system, in order to reduce the cost of holding inventory and the cost of replenishing the inventory.

The process that is measured is the internal part of the replenishment process at the Norwegian Navy Materiel Command, and the new approaches, design and measure and evaluation of these processes will be described in the following chapters.

V. ELECTRONIC COMMERCE

A. INTRODUCTION

> Electronic Commerce or EC, refers to the exchange of business information using electronic media such as, Electronic Data Interchange (EDI), E-mail, bulletin boards, Electronic Funds Transfer and other similar technologies [Ref.11].

This is maybe the one definition most often found on the Internet and in other publications where electronic commerce is frequently mentioned. This definition may however leave out a very important channel for the conduct of electronic commerce today and in the future; the Internet. Today the Internet is changing the way we do business with one another more quickly, and more radically, than any of us ever thought possible. According to Open Market Inc., Forrest Research found that by the end of 1996 80 percent of the Fortune 500 companies have their own Web-sites and 75 percent of the Fortune 1000 companies will offer online sales transactions by the end of year 2000 [Ref.12].

The same trend is seen in Norway. In many ways, the Norwegian appropriation of the Internet and multimedia technology can be looked upon as a rapid success story. *Business Week* has described the Scandinavian countries as being leading in the field of multimedia and the Internet in Europe, neck-to-neck with the US. The magazine even suggest that the business prospects in the near future, relatively speaking, are more promising in Norway than in the US [Ref.13]. While such speculations should not be taken too seriously, everybody nevertheless face the major challenge of accounting for a situation of rapid change.

B. WHAT EXACTLY IS ELECTRONIC COMMERCE ?

In this section electronic commerce (EC) is tried explained by using a theoretical replenishment/procurement process system as a tool to briefly picture the different components of electronic commerce.

The example is seen from the point of view of item managers. In his/her system electronic commerce is an established part of business. The item manager might access the EC system directly on a dedicated computer system, through an Intranet web site, or he or she might even go directly on the Internet with a system like for example Acquin's BASEsm [Ref. 24].

BASEsm is a buyer and seller exchange that combines Internet technology with detailed catalog and business listings to make purchasing products and services as easy as clicking a mouse. Through BASE, suppliers list their items and services online allowing free, easy buyer access. Buyers enter BASE via the Internet to perform quick, accurate keyword, part number, or category searches. The results of their search yields all the supplier's product details. Buyers can then create purchase orders and request quotations online.

It is also possible that the item manager is not directly involved in the purchasing process. An application like the inventory control system might automatically deliver a purchase order when it reaches the reorder point calculated by the system itself. Also other applications might trigger the electronic commerce system. Shaw [Ref. 23] says:

> Typical applications may include purchasing, accounts payable, general ledger, inventory, asset maintenance, cash management, order management, production scheduling and claims processing. Individuals themselves may initiate transactions, but increasingly applications will start transactions without human intervention. For example, an inventory control system may detect a reorder point, calculate an order quantity and pass a requisition to the purchasing system. The applications send messages to the an EC broker. Each message identifies the sender and recipient, the message type (purchase order, receipt, etc.) and the message contents. Messages are transported by a variety of methods (TCP/IP, X.400, SNA). The EC broker takes messages from the application and then translates, addresses, formats and routes them to the appropriate communications interface. Brokers use X.500 directory services to look up addresses and route messages to a fax number, Internet or E-mail address. For traditional Electronic Data Interchange (EDI), the EC broker would also create the appropriate EDI format. Acknowledgments and other responses are passed back to the EC broker for logging or forwarding back to the appropriate application. Other broker functions include archiving, reporting and auditing messages.

No matter if it is the item manager or any other application that trigger the replenishment/purchase one need to determine whether the item is established in the system; check if established vendors exists or whether one need to identify potential vendors. The item manager/ automated system needs to get availability and pricing. Further decide which vendor to place the order with, place the order and pay for the item, or confirm credit and finally verify receipt.

At each of these steps, the purchasing system's rules and regulations (especially in the military) may call for human intervention, but in the future transactions will probably become increasingly automated.

If potential vendors must be identified, the Electronic Commerce system may either launch a Web browser for human use or delegate intelligent software agents to search the Web. An intelligent software agent is a rules-based application that can transport itself from site to site over the Internet in search of requested information.

The organization will also need software that will provide an interface between their inventory/procurement system and the Web. Shaw [Ref. 23] says:

> A communications interface software module formats and transmits a message over one (or more) communications medium, be it an EDI mailbox, a fax, an Internet mailbox or an intelligent agent. It was designed as a separate software component to allow for additional EC media in the future. While the EC broker handles the authenticated information in plain text, the communications interface is responsible for all of the necessary security-related conversions.

As mentioned above, when the vendor is found the order will be placed. Payment can be conducted through credit cards (for example government credit card), digital cash transaction or confirmation of credit combined with traditional billing and payment. Authentication and encryption technologies are used.

If the goods being purchased is a physical good or service, confirmation of delivery will be communicated electronically within the organization and to the vendor. If the item is an information product or service, it will be delivered digitally.

To protect the companies own systems from outside interference, security measures like a corporate firewall has to be established. The corporate firewall protects data, messages

and other resources from the outside world. Some technologies such as the EDI mailbox and the corporate Web server exist both inside and outside the firewall.

According to Shaw [Ref. 23]; in the near term, many vendors may be contacted by traditional value-added network-based electronic data interchange (EDI), electronic mail or fax. In the longer term, intelligent agents launched by rules-based systems (for example future inventory control systems) will exchange most of the information over the Internet.

As this happens, EDI and E-mail response times will be reduced to minutes or even seconds. Vendors that cannot respond quickly and accurately will be unable to compete. In this way electronic commerce becomes a driving force for the development and transformation of business in the years to come.

C. EXPERIENCES WITH ELECTRONIC COMMERCE

This section will give examples of other organizations' experience with electronic commerce. In the United States the business sector as well as the government sector relay more and more on the electronic medium as a mean for conduct of business. For the government sector the real acceleration in this trend happened when the Federal Acquisition Streamlining Act of 1994 established the Federal Acquisition Computer Network (FACNET), and required government to evolve its acquisition process to EDI [Ref. 25].

The example below was taken from an online magazine called EDI-Online [Ref. 25], and shows how electronic commerce is helping government agencies streamline their procurement process by introducing electronic commerce practices:

> When it comes to making the procurement process more efficient and cost-effective, the General Services Administration's Federal Supply Service (GSA/FSS) increasingly is banking on EDI and Internet-accessible electronic catalogs to get the job done. EDI in and of itself has been a boon for GSA over the years because it has reduced paperwork, Teresa Sorrenti, director of acquisition operations and electronic commerce center for GSA/FSS told EDI INSIDER in an exclusive interview: We're at the point where only about five percent of our orders are [on] paper, printed out and mailed," she said. "We've converted all of our vendors either to EDI or to fax, if they're not ready. So we don't have anybody stuffing envelopes, mailing purchase orders; we've eliminated that aspect. We have an audit trail, we know that it went out. Even

> with the fax, we send something to them telling them how many orders they can anticipate for that day. Everybody knows what's coming and they know if they didn't get it. You don't have the type of situation where you think you mailed an order and when you call to see why you haven't gotten it, they haven't received it. It's a lot more certain that the information has gotten where it was supposed to go.

As mentioned in Section A, a very important channel for the conduct of electronic commerce now and in the future is the Internet. Several companies have experienced that the Internet can be an important way of streamlining procurement, and more specially of interest to this thesis, reduce lead-time. An example of how much a company can reduce its lead-time with use of electronic commerce over the Internet is given below. This story was taken from EC Riders - CIO Magazine [Ref. 26].

> At GE Lighting, electronic commerce was the key to creating a streamlined procurement system that is integrated with the firm's 55 machine parts suppliers. Until recently, the requisitioning process from the plants was initiated electronically via the existing purchasing system. The purchasing agents would review daily requests and initiate the price-quoting process. The engineering drawings of the part and an electronic quote form were requested, and the packages were prepared. Simply fulfilling a request for quotation could take several days, and the division typically issued 100 to 150 such requests a week. The company then mailed the completed requests to suppliers. "Some people in the machine parts unit were basically just stuffing envelopes all day," says Ronald Stettler, manager of global sourcing systems. In all, GE Lighting's procurement process could take as long as 22 days. Today, however, GE Lighting is transforming that kludgy, antiquated process into a streamlined one that takes about eight days. How? It started using the Trading Partners Network (TPN), an extranet developed by sister division GE Information Services (GEIS), a Rockville, Md.-based provider of electronic commerce services. By integrating TPN into its legacy procurement system, GE Lighting gained the ability to let suppliers view the requests on the extranet shortly after buyers in the worldwide sourcing division post them. Suppliers can then post blind bids using TPN. GE Lighting's project to integrate procurement systems with TPN took six IS people about three months to complete. Though IS had to do some C coding, the most challenging part of the project was coordinating the new process because so many people-buyers, engineers and suppliers-needed to give their input, Stettler says. Working with suppliers to make sure they were comfortable with the TPN interface prototype was a key success factor, he says. GE Lighting had close relationships with suppliers before, but with the network, those alliances have become even stronger. For example, it is

> not unheard of for the GEIS technicians to drive through snowstorms to reload Windows on a supplier's TPN PC just to get the supplier back online so it can make bids. By using TPN, several General Electric divisions, including GE Lighting, have, on average, cut procurement cycles in half, reduced procurement processing costs by 30 percent and induced suppliers to reduce prices due to online bidding, according to Bruce Chovnick, vice president of Internet consulting services for GEIS. Chovnick wonders why more companies haven't set up similar systems. "A lot of companies think about it for too long," he says. "The investments aren't that big." He recommends that CIOs stop dithering and build an extranet prototype, pronto. Then, he says, "the ROI becomes very obvious."

A reduction of procurement lead-time by one-half and reduction of processing cost of 30 percent can probably be added by reduction in safety stock held by the company. This means that the savings potential probably was even bigger than what the article suggested.

To follow up on savings potential due to electronic commerce, the list presented in Table 1, are some examples of cost saving within administration and management, and reduction in use of "paper-processes". The list was completed through research of the benefits of electronic commerce done by Easy EDI [Ref. 27].

As one can see from the list, Long Island Medical Center as one example, experienced an inventory reduction of 25 percent over a two year period. And what the list does not say, is that in that same period the Medical Center had an increase of more than 50 percent in the number of orders processed in the same period [Ref. 27].

All the experiences given in this section, show that the benefits from electronic commerce can be substantial also for a government organization like for example the Royal Norwegian Navy Materiel Command.

Table 1. Experienced Cost Savings from Use of EC

Pacific Telesis (PACTEL)	Cost per transaction from $78.00 to $0.48
Texas Instrument (TI)	Average costs to process a PO from $49.00 to $4.70
R.J Reynolds	99.5% reduction in cost of purchase orders
J.C Penneys	Over $1 million saved in postage costs annually
K-Mart	84% reduction from the cost of a manual purchase order to that of an EDI purchase order
SuperValu	Savings $6,000 per day in purchase order-receiving invoice reconciliation costs
Health Industry Business Communication Councils (HIBCC)	A typical purchase order costs hospitals about $40 to process(if that PO is sent using a vendor's Electronic Order Entry (EOE) system, hospitals spend $30.40). With EDI, the cost to process a PO drops to an amazingly low $11.20 each and hospitals save $28.80 for each PO.
Long Island Medical Center	Inventory reduced by 25 percent over 2 year period
Bank of Chicago	Savings between $3.75 and $6.50 per document
Big Four U.S. Automobile Producers	Saving at $200 on each car produced
The Automobile Industry Action Group	Costs of processing purchase orders at $50.00-$75.00 reduces to $12.00
VA	- Cost per invoice from $3.48 to $1.55 (net savings of $12 millions discounted over 5 years). - Cost per Government Bill of Lading (GBLs) from $10.07 to $4.52 each
The Department of Defense	In its business case for electronic commerce, $1.2 billion in saving by automating 16 most-used forms over a 10 year period.
The Defense Logistics Agency General Supply Center (in Richmond)	$24.5 millions in savings with its Paperless Order Processing System (POPS) which eliminated paperwork and reduced inventory and depot costs
Department of Commerce	99% reduction in paper processed by the Bureau of Export Administration in the issuance of export licenses

D. THE INTERNET IN NORWAY

In order to pursue the idea of electronic commerce over the Internet as an possible idea for the procurement of inventory items at the Navy Materiel Command, this section will describe the position of the Internet currently experienced in Norway.

Arguably, Norway is a perfect spot for the diffusion of information technology. Besides the fact that its population is small, 4.37 million inhabitants, it is sparsely populated, with a population density of 14.2 persons per square kilometer. Situated at the northern periphery of Europe, its extension in a north-south direction is comparable to that of continental Europe from Denmark to the southern tip of Italy. In addition to its extreme length

the country is also very mountainous with only four percent arable land and many fjord incisions [Ref. 17].

Thus, to overcome the topographical challenges, the need for modern telecommunications is considerable. In the 1990s the Norwegian Telecom (Telenor), has been transformed from a branch of public administration into a business-oriented company. Even if digitalization of the telephone network is yet to be completed, Norway is now fairly advanced both in terms of technology, number of telephones per capita and even the costs of using telephone services. Moreover, the penetration of cellular telephones is among the largest in the world [Ref. 13].

In May 1997, a total of 200,000 private Internet user connections had been sold by various access providers, and more than one million Norwegian had access to the Internet (about 25 percent of the population). Furthermore, more than 160,000 persons would be logging on daily, as opposed to 63,000 persons one year earlier. It is expected that the number of Norwegian households with Internet connections will be close to 440,000 homes in May 1998. As a result, Norway will end up with one of the highest Internet densities in Europe, according to this Gallup survey made in the spring of 1997 [Ref. 17].

E. REENGINEERING AT THE MATERIEL COMMAND WITH ELECTRONIC COMMERCE

In this section a description of how it might be possible to redesign the replenishment process at the Navy Materiel Command with electronic commerce over the Internet will be given.

Within the Logistics Division , briefly described in Chapter III, the Navy Materiel Command has six item officer offices that handle the replenishment of material to the supply system, in cooperation with a procurement department. Each office has a number of manual catalogs from a number of vendors, both Norwegian and foreign. Most communication, ordering etc. is manual processes. The entire process is, as is shown in Chapter VII, generally

time consuming and therefore perceived expensive in the form of safety stock needs and extended use of manual labor.

What would it be like if the Material Command personnel could find the needed information in an online catalog? By clicking from one screen to the next, he or she could narrow down the search in a matter of minutes or even seconds. No longer would it be necessary to go through hundreds maybe even thousands of pages of printed material to find an answer. As long as the online catalog is easy to navigate through, identifying the right part or supply would be very easy indeed, compared to the paper method. Depending on the sophistication of the catalog and its links, the item manager may even find special contract pricing and the like. And the system may be able to link an order to the purchasing, order entry, and accounts payable departments. The time and cost savings in such a scenario would be large.

By eliminating paper copies of orders, invoices, past due statements, and the like, one will spend less time rekeying information into different computers and correcting the inevitable errors.

It is known, that online catalogs have been around for years without much ado. The problem is that online catalogs of yesteryear were largely proprietary, requiring buyers to have special software and limiting the functions that could be performed on line. Such "end-to-end" commerce is heavily dependent on tight integration of computer systems of both the buyer and the vendor.

What is the alternative? One alternative being used more and more is the Internet. Around the globe, an increasing number of business-to-business firms are beginning to leverage its potential. Today's Internet channel enables business-to-business prospects and customers to:

- Enter a vendors Web-site, identify themselves and gain confidential access to authorized information.
- Use flexible navigation tools to rapidly identify the exact product or products they are seeking—in a matter of seconds.

- Access all the in-depth product information to compare products or determine if a part meets their exact specifications.

- Obtain accurate, customer-specific pricing.

- Check product availability.

- Review total order costs including tax and shipping expenses.

- Order with the click of a button.

- Choose from a number of payment methods – personal, corporate or government credit card, purchase order or an established account.

- Track the status of an order until it is delivered.

An Internet system can also reduce labor costs. The Materiel Command will be able to place and check their orders on line, without assistance from the vendor's sales or customer service personnel. Further, checking for available items, placing of orders and paying for items can be done without to much detail knowledge on purchasing practices and can therefore be conducted by the item managers without any assistance from a separate procurement department. The procurement department might be needed to set up blanket-contacts[2] or similar contracts in order to allow for procurement over the Internet without having to fundamentally change current rules and regulations for Navy purchasing. By eliminating human intervention and the inevitable mistakes, costs and frustration can be decreased.

Is it possible for the Material Command to get its vendors to provide catalogs on the Internet, accept electronic transfer of funds and so on? This might actually only be a question of time. Since Norway is heavily into telecommunications and the Internet, companies will start to build on-line catalogs due to the potentials of increased revenues. A Web-based catalog can be viewed from every desktop throughout the vendor's existing customers' organizations, not just by a single purchasing agent or department. In addition, a Web-based catalog can be made

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2 A blanket order is a contract to purchase certain items from the vendor. It is not an authorization to ship anything. Shipment is made only upon receipt of an agreed-upon document, perhaps a shipping requisition or shipment release etc. [Ref. 18 P. 539]

available to prospects around the world, enabling the firm to tap markets they couldn't afford to cover through traditional means.

But if the Material Command vendors need a push to get started, the buying power of the Material Command is significant, and vendors that are not willing to play can in most cases be cut of as vendors. In any case if only the major vendors can provide on-line catalogs the effort might still be worth while.

VI. SIMULATION MODELING

A. INTRODUCTION

This chapter will build on the process redesign approach described in Section D of Chapter IV. The objective is to find if it is possible to reduce administrative lead-time through the redesign of existing replenishment process. Existing replenishment process will be simulated in the simulation language Arena. Then two new approaches to the existing process will be introduced, and finally the findings will be measured.

What is simulation? Kelton, Sadowski and Sadowski define simulation in the following way [Ref.20]:

> Simulation refers to a broad collection of methods and applications to mimic the behavior of real systems, usually on a computer with appropriate software. In fact "simulation" can be extremely general term since the idea applies across many fields, industries, and applications. These days, simulation is more popular and powerful than ever since computers and software are better than ever.

The definition shows that what one are trying to do through simulation, is to build a real world system into a representative model, that can be handled by a computer. This is done in order to evaluate and possibly improve the existing system without having to use a continuous real life trail and error process.

B. CLASSIFYING THE PROBLEM

It is only natural that different problems need different approaches, also in form of the simulation model used. There are several ways to classify simulation models, but to classify the model into three main classification areas is a much used and well known method [Ref. 20]. In the following the replenishment problem will be classified by applying this technique.

1. Static Versus Dynamic

In static modeling time does not play a major role or not a role at all. It is known that the probability of getting for example the number three when a die is tossed, is one sixth. This could also have been shown with a static simulation; If the die had been tossed a large number of times, and then the number of times the number three appeared had been counted for then to be divided by the number of times the die was tossed, one would end up with one sixth or something very close. Time plays no role in this simulation and the simulation is therefor static.

The replenishment process at the Norwegian Navy Materiel Command is a process where time to process replenishment proposals, procurement orders and other tasks in the replenishment will change all the time. Time becomes a major player in the way the model is develop. This form of simulation needs therefore a dynamic model that can, and will change.

2. Continuous Versus Discrete

In a continuous model, the state of the system can change continuously over time like a river that continuously changes its depth due to rainfall, drought and other continuously ongoing events.

In a discrete model like in the simulation of the replenishment of inventory items, a discrete event must occur for the system to change. For example will the item managers not continuously work with proposals for replenishment. The discrete event of proposals arriving in the office must occur before change takes place.

3. Deterministic versus Stochastic

If the demand for a firm's products were known for sure, both in form of size, place and time demand could be said to be deterministic. And then as mentioned before, if products could be supplied instantaneously to meet the demand, theoretically storage would not be required since no inventories would be held.

However this is not the case, demand for products in the Navy's inventory which again make it necessary for the Navy to replenish the inventory, is based on some kind of probability distribution. This is the case with stochastic models, in stochastic models the inputs are random variables, and hence the output will also be a random. In the replenishment model there will be

deterministic elements, like for example that the computer system generates replenishment proposals every 14 days, but most events will be highly stochastic.

4. Short Summary of the Classification

By classifying the problem through the three major classifications described above it was found that the replenishment problem is a combination of dynamic, stochastic and discrete events. This kind of simulation problem is called a discrete events simulation and can be solved by a simulation language like for example Arena.

C. THE SIMULATION LANGUAGE ARENA

Without going to deep into the background and history of computer simulations, it can be said that computer simulations have up until very recently, been the play ground of programmers and experts with in depth knowledge of special purpose simulation languages like SLAM and SIMAN. This is starting to change, and the ease of use with simulation languages like Arena contributes to this happening.

Arena is an object-oriented language. This means that a lot of the programming effort needed with special purpose simulation languages is already done. What one will have to do is select objects/modules and than operate on the objects. The bottom line is that even if it still is not done in a day to learn how to simulate, the level is reduced considerable with easy to use object oriented languages like Arena.

D. WHY SIMULATE

Assuming that it is of interest to find out something about a system, there are several different ways to do this. One can for example experiment with the actual system or with a model of the system. If it is decided to use a model of the real system, the model can either be built as a physical model or constructed as a mathematical model. The mathematical model can again be divided into two alternatives. An analytical solution like for example linear regression can be applied, or finally computer simulation can be used.

Compared to experimenting with the actual system Pidd [Ref. 21] says, that simulation has the following advantages:

- Cost: Though simulation can be time consuming and therefore expensive in terms of skilled manpower, real experiments may also turn out to be expensive, particularly if something goes wrong.

- Time: Admittedly, it takes time to produce working computer programs for simulations model. However, once these are written then an attractive opportunity presents itself. Namely it is possible to simulate weeks, months or even years in seconds of computer time. Hence a whole range of policies may be properly compared.

- Replication: Unfortunately, the real world is rarely kind enough to allow precise replications of an experiment. One of the skills employed by physical scientists is the design of experiments which are repeatable by other scientists. This is rarely possible in management science. It seems unlikely that an organization's competitors will sit idle by as a whole variety of pricing policies are attempted in a bid to find the best. It is even less likely that a military adversary will allow a replay of a battle. Simulations are precisely repeatable.

- Safety: One of the objectives of a simulation study may be to estimate the effect of extreme conditions, and to do this in real life may be dangerous or even illegal.

It can be mentioned that the advantages that Pidd points out/ are based on simulations conducted with special purpose simulation languages, that takes longer time to build than object oriented languages like Arena. This means that the magnitude of the advantages in most cases are even better now that object oriented simulation becomes more and more common. The advantages with simulation versus experimenting with the real system can also in a large extent be applied to physical models of the real system. In many cases the alternative of building a physical model will not even be an alternative, specially within management science. It would probably gain very little to try to build a physical model of the Norwegian Navy's replenishment process of inventory items.

Assuming that it has been decided that a mathematical model should be used to research the replenishment problem, will simulation be better than "traditional" mathematical models like for example regression analysis? Pidd [Ref. 21], says:

Traditional mathematical models cannot satisfactorily cope with dynamic or transient effects. For example, the steady-state behavior of a paint-shop may be of less concern to a motor manufacturer than the operation of the system after breakdowns. Second, though it is debatable whether this is a good thing, it is possible to sample from non-standard probability distributions in a simulation model. However, queuing theory models permit only certain distributions and therefore cannot cope with many types of problems.

The main point from Pidd that applies to the replenishment problem, is the problem traditional mathematical models has with the dynamics of the system. Remembering that the replenishment problem was classified as, discrete, stochastic and dynamic events, it is clear that a simulation approach is needed.

E. DESIGN AND CONCEPTS OF THE SIMULATION

In this section a description of the approach to input variables used in this dynamic discrete event simulation will be given. Further a short description of how the output variables generated by the simulation model are handled is included.

1. Input Variables

To make a simulation model of a system or process work, in most cases random variable inputs defined by an underlying probability distribution is needed. The probability distribution is used as a way to model real world behavior, and it is therefore important to obtain as good data as possible in order to decide which distribution best reflect the real world.

The estimation of probability distribution and its appropriate parameters can be separated into two main methods [Ref. 22]:

- Collect data from an existing source. Using standard techniques of statistical inference, a distribution is selected which "fits" the data (It can be mentioned that Arena has a input-analyzer that will help the researcher to "fit" data to a distribution).

- Use a heuristic approach for choosing a distribution in the absence of data (or enough data), along with expert opinion to estimate input variables.

In this thesis the heuristic approach is used for choosing distribution for all processes which represent random variables. It was not possible to obtain enough "raw" data to fit data by statistical inference. The Royal Norwegian Navy Materiel Command provided however, expert opinion on the processes of the existing system. Range and most likely value of desired parameters on most processes within the model were obtained in association with the research. On the rest of the processes, a mean value or range were found. Personal experience with the Materiel Command were also helpful in the work to get best possible parameters.

All processes within the model, except the number of replenishment proposals generated, are representations of activities. Kelton, Sadowski and Sadowski say that [Ref. 20]:

> If the times represent an activity where there is a most likely time with some variation around it, the triangular and normal distributions are often used because they can capture processes with small or large degrees of variability and their parameters are fairly easy to understand. The triangular distribution is defined by minimum, most likely, and maximum values, which is a natural way to estimate the time required for some activity. It has the advantage of allowing a non-symmetric distribution of values around the most likely, which is commonly encountered in real processes. It is also a bounded distribution, no value will be less than the minimum or greater than the maximum, which may or may not be a good representation of the real process.

Triangular distribution is chosen for the activities in the simulation model.

In the two redesign approaches of the existing system, the changes in input data, are based on other organizations experiences and on conducted sensitivity analysis of the changes. More on this in Section F, Sub-section Three and Four.

2. Output Variables

The simulation model of this thesis simulates a system that will not be terminated but continue to work over time. In simulation, such systems are called non-terminating systems [Ref. 20]. Most non-terminating system must go trough a transient phase (a warm-up period), prior to reaching steady-state behavior for the system.

Because of this, data collected during the initial portion of the simulation are discarded, and hence biased observations from the warm-up period are avoided. This is done by setting a

number of simulation runs (replications) in Arena as warm-up periods, where no statistics are gathered.

Since the simulation is on a non-terminating system the system is not initialize when one simulation run is done. The system will therefore develop over the number of replications chosen for the entire simulation. However, the statistical data gathered from the simulation must be a representation of each replication and hence statistical data gathering will be initialized between each replication.

The statistical data that gather during the total simulation run are saved to an output file in Arena, where they can be retrieved to be used in Arena's output analyzer. Kelton, Sadowski and Sadowski say [Ref. 20]:

> The Arena Output Analyzer provides the capability to post-analyze simulation data that were saved to an output file during a simulation run. It provides the ability to display these data, as well as to analyze and draw statistical conclusions about the data.

The one output variable that is of most interest to this thesis is the variable that measure the prime performance criterion, administrative lead-time. It is this out-put variable that will be of highest concern in the analysis of the simulation given in Chapter VII. Also other variables, like time to perform individual activities within the total replenishment process, number of replenishments conducted and utilization of personnel will be of interest.

F. DESCRIBING THE SCENARIOS

In this section the replenishment process as it is today will be described, and a description of the proposals for redesigning the process will also be included. The description of the existing process is based on a set of questions answered by the different offices and departments involved in the replenishment process at the Materiel Command.

1. Short System Description

Every second Thursday the computer system generates proposals for replenishment of articles that has reached their reorder point (R). The proposals are routed to the item manager

offices/groups at the Logistics Division. The item managers are divided into six offices/groups, based on the category of the items they are in charge of. The six different offices are:

- Hull and Ship Parts Office
- General Supply Office
- Weapon Parts Office
- Electronics Office
- Navigational Parts Office
- Petroleum, Oil and Lubrication Office

In these offices one or two naval officers are responsible for the proposal. They will finally decides whether to cancel the proposal or to allow it to proceed (sign it). In this decision process they will for example check if the Materiel Command already has a vendor, if this vendor has a good history with the Command. Is the information on the vendor up to date in the computer system? They will control the demand history of the item, how the computer inventory model is working for the item. It is important to realize that this is only examples of what they might do in the process of checking and controlling the replenishment proposals.

Proposals with a total procurement sum below Norwegian Krone (NOK) 150,000, which is about $ 21,500, are handled by two procurers in the Internal Procurement Office, situated in the same building as the item managers. Their part of the replenishment orders make up about 40 percent of the orders.

The rest of the proposals are shipped electronically to the Procurement Department that is a part of the Materiel Command's Staff. The Staff is located in a building about half a mile from the Logistics Division. At the Procurement Department, the procurement personnel looks over the proposal and finally decides what vendor to use. The proposals are then written on to buying-forms and mailed or faxed to the vendor. The same process is used by the Internal Procurement Office.

When parts are received from vendors, they are first checked by the Receiving Department that is a part of the Logistics Division but separately located. Then the invoice is sent manually to the Staff for payment, before it is electronically sent to the Logistics Division's Supply Department for entering into the supply system. Figure 12 shows a flow diagram of the system shows how information and materiel goes through the system.

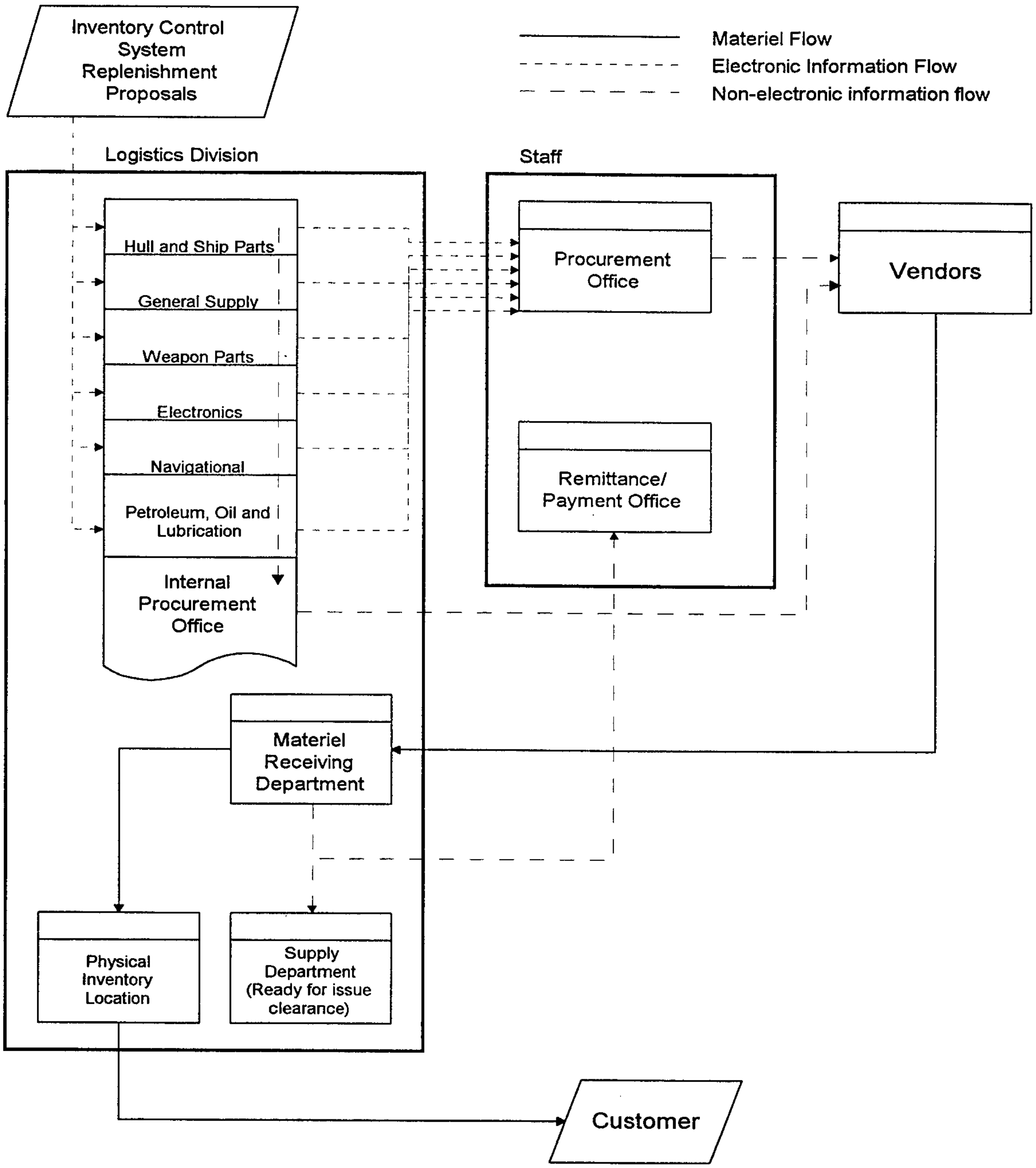

Figure 12. Information and Materiel Flow

2. The Base Model

The base model is built according to the system description. To better explain how the model is built a picture of the pre-programmed object that has been used is shown in Figure 13.

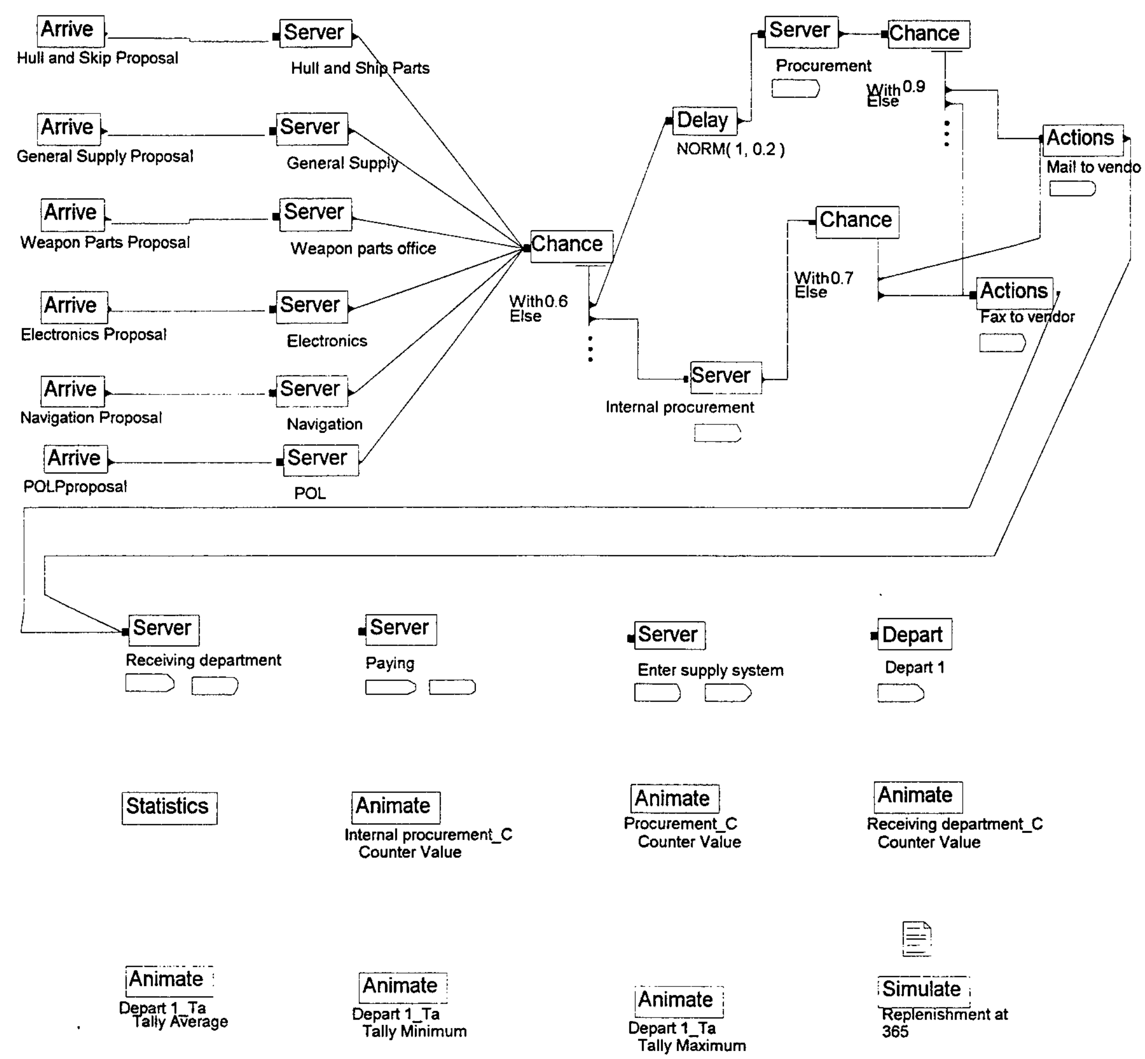

Figure 13. The Base Model

The logic of the model start in the upper left corner with six Arrive modules. The Arrive module is the "birth" node for arrivals of entities into the model from outside. In this case, the Arrive modules simulates the arrival of the replenishment proposal received by the six different item manager offices. The six offices are:

- Hull and Ship Parts Office
- General Supply Office
- Weapon Parts Office
- Electronics Office
- Navigational Parts Office
- Petroleum, Oil and Lubrication Office

The time between arrival are 14 days (deterministic, hence no probability distribution). Each time a proposal arrives it is marked with its arrival time into the system, so that the model can measure the time it use through the system. In this way administrative lead-time can be measured.

The next modules in the model are the six different item manager office server modules. These server modules represent one item manager office each. They include the resource and processing time required to "check" the proposal. The resource represented in the modules are in this case the office itself, not the individual officer. Triangular distribution was chosen with minimum time used to process a proposal of about three minutes (or 0.007 days out of a work day of seven and a half hour). The mode was set to be around 14-15 minutes (0.03 days), and the maximum time five weeks. These times were provided by the Materiel Command. A sensitivity test of the model with 35 days as maximum process time was conducted, and it was found that the Triangular distribution with this maximum, generated longer process times on average than what the Navy Materiel Command had said to be the

case. In order to not overstate the possibility of long process times in the item managers' offices the maximum time in the server modules are therefore reduced from 35 days to 30 days.

As mentioned in last sub-section, about 40 percent of the proposals include replenishment of less than 20,000 dollars, and can therefore, according to Norwegian Navy rules and regulations be handled by the Internal Procurement Office, situated along with the item managers' offices. This is simulated in the model with a "chance" statement (or probabilistic branching), that transfer 60 percent of the proposals to the Procurement Department (Staff), and 40 percent to the Internal Procurement Office (Logistics Division).

The Internal Procurement Office is simulated with a server module, that has a capacity of two workers, and a triangular distributed process time of minimum 45 minutes (0.1 days), mode of one day and maximum of two and a half days.

The Procurement Department is situated at the Materiel Command's Staff building, which is located about 0.5 miles away from the Logistics Division's main building. The Internal Procurement Office is situated at the same place as the item managers, and hence will experience virtually no delay from the time the proposal is signed by the item manager until they receive it. However this is not the case for the Procurement Department. Although the signed proposals are transferred electronically, some delay in form of the procurement personnel working on other matters, and hence not being able to receive, will occur. A normally distributed delay time with a mean of one day and a standard deviation of 90 minutes is assumed in the model.

At the Procurement Department, five persons have the responsibility for replenishment procurements. We used a Triangular distributed process time of minimum one day, a mode of five days and a maximum of 14 days. The Internal Procurement Office has a shorter process time, first, they handle more standard replenishments with total sums not higher that 20,000 dollars; secondly their only mission is to conduct replenishment of inventory items for the Logistics Division. The Procurement Division (Staff), on the other hand, handle all kinds of procurements for the entire Materiel Command and several other institutions.

It is estimated that 30 percent of the procurement orders are faxed to the vendors from the Internal Procurement Office, and 10 percent are faxed from the Procurement Department to vendors. The rest of the orders, are assumed to be shipped by mail. Two "chance" statements reflect the division between faxing and mailing in the model.

From the definition of Administrative lead-time, it can be seen that all time consumed, including shipping/mailing, up until the vendor receive the order is the first part of the administrative lead-time. This is simulated in the model by including two "action" statements. The first action statement, simulates the time it take for an order to reach a vendor by mail. The time is Triangular distributed with a minimum of one day, a mode of three days and a maximum time (including both national and international vendors) of 10 days to reach the vendor.

The time to fax an order, naturally takes less time. But since the order must be acknowledge by the vendor before it is no longer considered administrative lead-time, the maximum faxing time is set to one day, the mode, four hours and, the minimum time 45 minutes.

The next module in the simulation model is the server representing the Receiving Department. When material is delivered by the vendors, the Receiving Department use three workers to check the delivery against the order. They have a Triangular distributed process time with a minimum of 45 minutes, a mode of one day and a maximum of five days.

From the Receiving Department, the papers concerning the received goods, are transferred to the Staff, so that the invoice can be cleared (paid). The time to conduct this transfer, is assumed to take 90 minutes.

The received parts will be distributed to their respective inventory locations, and the supply system/inventory control system can be updated. This is simulated in the model, with a server module called "Enter Supply System". The module has a capacity of three workers with a Triangular distributed process time of minimum four and a half minute, a mode of one day and a maximum of five days.

The entity (proposal/order) has now been through the total administrative loop (the simulated system), and is released from the model with a "depart" module. In the depart module, the time the entity has used through the system is measured, and administrative lead-time for the entity can be found.

As can be seen from the picture of the model, several other modules are also included in the model.

The "Animate" modules are used to animate different aspects of the simulation. More on this is Section G.

The "Statistics" module collects statistics on the time used by the entity at the different modules of the simulation model. It collects the data on the minimum, average and maximum administrative lead-time experienced through the simulation as well as the standard deviation of the lead-time. The data collected is saved to different output files, as mentioned in Section D, to be used in comparative analysis of the simulation results (See Chapter VII).

The last module in the base model, is the "Simulate" module. In this module, the run length, and number of replications and other simulation experiment parameters are specified (more on this in Section H).

The following sub-sections will explain the different embellishments that have been built in a redesign effort of current replenishment system, with the goal of reducing administrative lead-time.

3. The Consolidation Model

The first redesign effort of existing replenishment process, builds on a process that has already partly started at the Norwegian Navy Materiel Command.

If this research had been conducted ten years ago, one would have found that there were no Internal Procurement Office at the Logistics Division at all. According to the Logistics Division, the establishment of procurement personnel at the division, has already reduced the administrative lead-time. They further think that by conducting all procurement of inventory items to the supply system from the Logistics Division will reduce administrative lead-time more. This is what this embellishment of the replenishment process is trying to model.

The picture of the model in Figure 14, will be used to point out where the changes have been made from the base model (existing system).

Shown in Figure 14, the Procurement Department is deleted from the model. In this embellishment two of five Procurement Department (Staff) personnel involved in the process of replenishment are consolidated with the existing personnel at the Internal Procurement Office (Logistics Division). This offices is located right beside the item managers' offices at the Logistics Division. Personnel at The Procurement Department, that before was dedicated to replenishment of inventory items, can be given other tasks in the organization or laid off.

The process time is assumed to change, since all procurement tasks, from the "easy" ones to the more complicated ones, are now conducted by the Internal Procurement Office. An extrapolation of existing process times was used to come up with a triangular distributed process time of minimum 45 minutes, a mode of two and a half day and a maximum of seven days. These times are extrapolated from the existing times at the Internal Procurement Office and the Procurement Department described in last sub-section. Sensitivity analysis of the process time has also been conducted, by changing the lead-times to create different scenarios. Results from the sensitivity analysis can be found in Section H, and further discussion in Chapter VII.

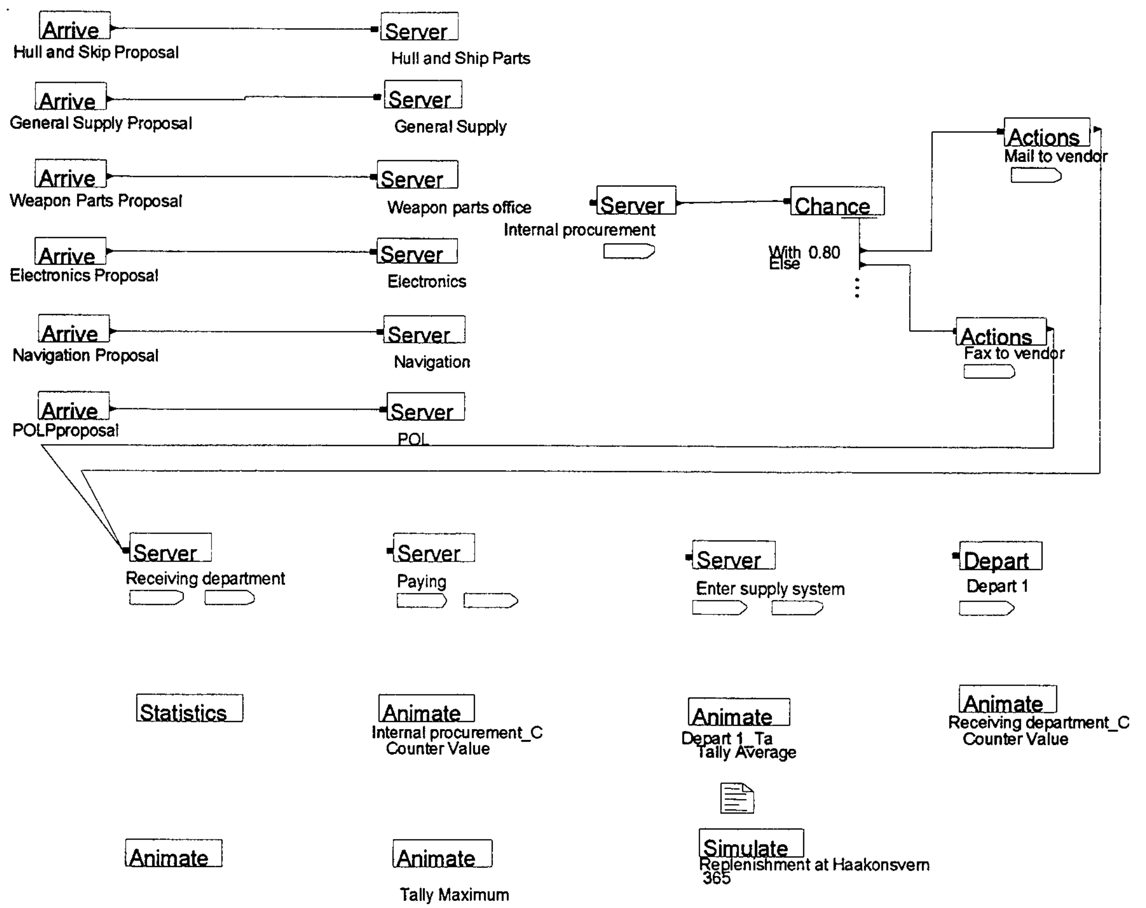

Figure 14. The Consolidation Model

The percentage division of orders going by mail and over fax is simply a combination of the different percentages found in the base model, rounded to the closes "round" number. Different scenarios have been conducted here also.

All other processes throughout the model remain unchanged from the base model (existing system).

4. The Electronic Commerce Model

This section is modeling what was described in Chapter V of this thesis, Electronic Commerce.

In Chapter V, Section E, it was described how an item manager could order directly from a vendor without any assistance from a separate procurement department with Electronic Commerce. This fact is reflected in the model pictured in Figure 15:

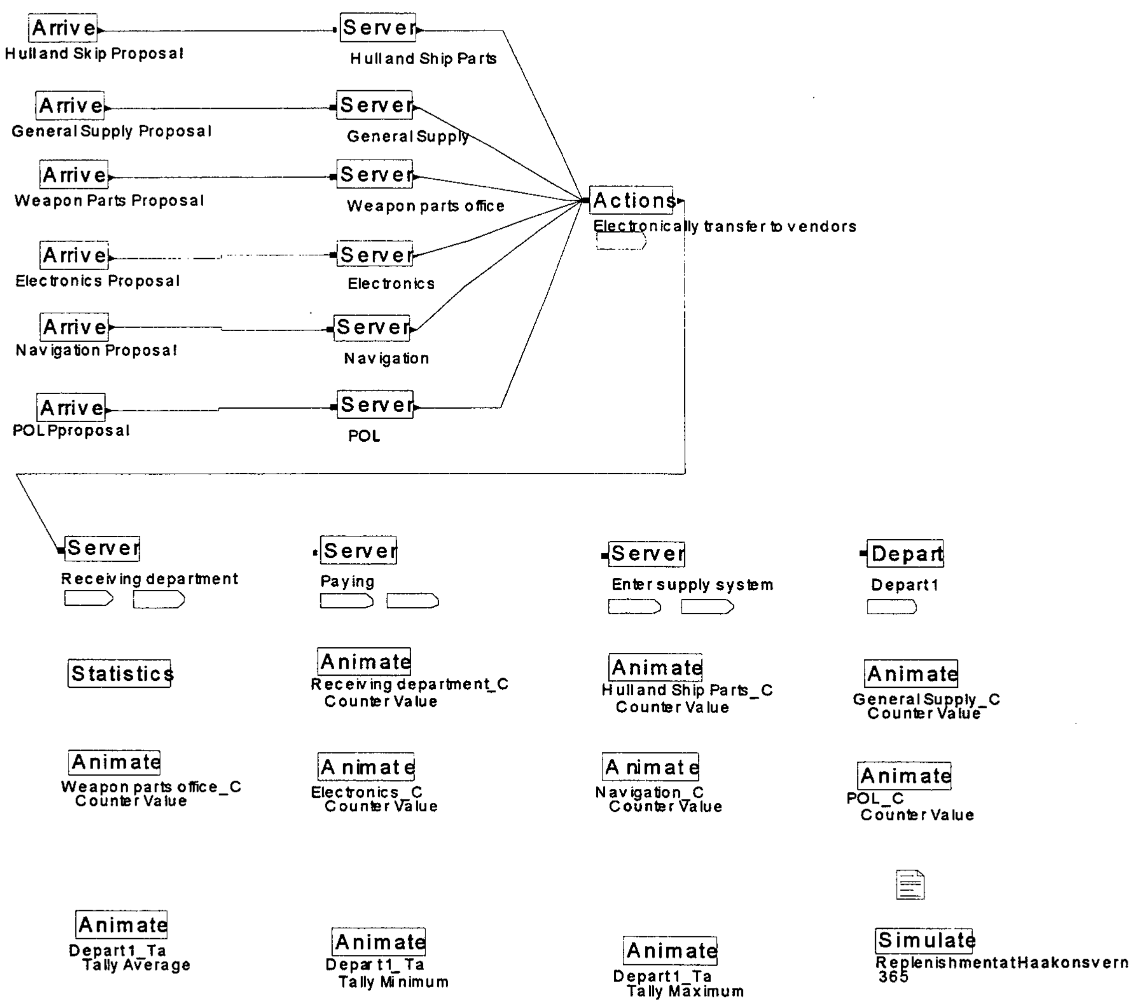

Figure 15. The Electronic Commerce Model

Shown in Figure 15, the electronic commerce replaced the mailing process. An "*actions*" statement simulates the time it will take for the item managers to transfer data to vendors. This time is set to be triangular distributed with a minimum of four and a half minutes, a mode of about 25 minutes and a maximum of one day. These times do not reflect only the transmitting time, but also the time for the vendors to recognize that an order has been received.

Chapter V showed how other companies have experimenting with and/or implemented electronic commerce and found that the process times at item managers have been substantially reduced. Electronic payment will also significantly reduce the administrative lead-time.

In this thesis, different scenarios are evaluated, from no change in item manager process times and unchanged payment method/time, to substantial reduction in process times and use of electronic payment methods. Results from these scenarios can be found in Section H, and further discussion in Chapter VII.

G. ANIMATING THE MODELS

This section will shortly explain why animating the simulation model is important. Figure 16 is a sample of the animation done on this thesis' simulation models. A Figure of the animated consolidation model can be seen in Appendix C, Section A, and Appendix D, Section A shows the animated electronic commerce model.

Animation is designed primarily for communication between the decision maker and the analyst. Animation of a simulation model can be very important, especially if one would like to "sell" an idea because; "a picture is worth one thousand words." In Figure 16 a picture of the animated base model can be seen:

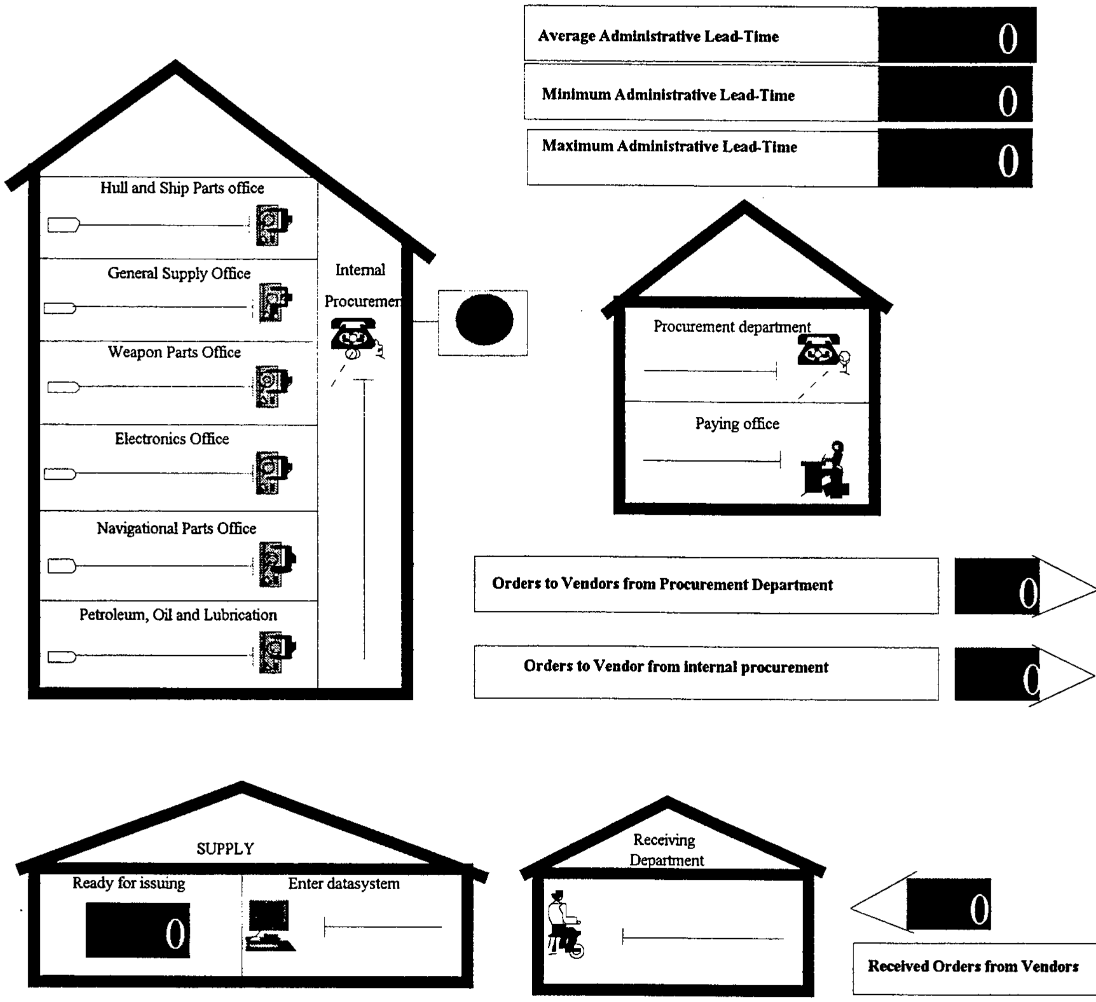

Figure 16. Animation of the Base Model

As one can see, the main interest in this simulation is the administrative lead-time generated by the simulated replenishment process. The animation will throughout the simulation show the current maximum, minimum and average administrative lead-time experienced.

Besides this, each resource (e.g., the item manager offices and Procurement Department) is animated with one distinct picture shown when the resource is idle, and one when the resource is busy. In this way, the viewer can get a feel for how the system is working and if any resources are more idle than others.

Each server, from the item managers' offices until the "enter supply/data system", will also display a queue. In this queue the entities (the proposals/orders) will line up before they are processed. In this way, the viewer can see if, for example extra, resources is needed because the queue becomes long.

Lines between the servers, where the entities moves could also be made. This is not done in this simulation model, because this is not important for this "business" process.

H. SIMULATION MODELS AND RESULTS

This section will explain how the simulation was run, and provide the main results from the different simulation model scenarios.

1. Running the Simulation

The simulation run length was set to 365 days (one year), with twelve replications of each 365 day run length, and two warm-up periods.

As mentioned in Section E, the first two replications was not included in the gathering of data. This was to avoid biased observations from the initial transient period. After each completed simulation run of the different models and model scenarios, statistical data gathered during the run was evaluated. Further discussion of the collected data is presented in Chapter VII.

2. Simulation Results

Results concerning administrative lead-time found through the simulation runs are provided in Table 2. For each scenario, an average of the results found in each of the twelve replications used for data collection (the 2 warm-up periods were discarded) are presented. The five main identifiers presented for each scenario are, the average administrative lead-time, minimum, maximum and standard deviation. The average result of each identifier in each of the twelve simulation runs, was summed together and then divided by twelve to obtain a overall average. The half widths of a 95 % confidence interval of estimates are also included. Comparative analysis of the results can be found in Chapter VII.

a. *Administrative lead-time (Existing System)*

The base model (existing system) was run exactly as described in Section F, Sub-Section Two. Following results were obtained:

Table 2. Base Model Results

(BASE MODEL)		95% C.I		
Identifier	Average	Half-width	Minimum	Maximum
Average Administrative Lead-Time	28.943	0.70852	27.034	30.968
Minimum Administrative Lead-Time	9.0279	0.96559	5.7426	11.209
Maximum Administrative Lead-Time	57.629	3.3765	47.929	69.951
Standard Deviation of Adm Lead-Time	10.223	0.38828	9.2891	11.654

b. *Administrative lead-time (Consolidation Model)*

This model was run under three different scenarios. The first scenario started with the scenario described in Section F, Sub-Section Three. The model had a Internal Procurement process time of minimum 45 minutes, a mode of two and a half day and a maximum of seven days. The percentage division of orders going by mail and over fax were set to 80 percent and 20 percent, respectively. Following results were obtained:

Table 3. The Consolidation Model, Scenario 1 Results

(CONSOLIDATION SCENARIO 1)		95% C.I		
Identifier	Average	Half-width	Minimum	Maximum
Average Administrative Lead-Time	26.303	0.84575	24.197	28.534
Minimum Administrative Lead-Time	9.5212	0.98056	6.081	12.106
Maximum Administrative Lead-Time	55.892	4.3984	44.404	67.872
Standard Deviation of Adm Lead-Time	9.3088	0.73858	6.8663	11.843

In the second scenario, the minimum process time was changed to 22 minutes, the mode was set to one and a half day and the maximum was left unchanged at seven days. The results of this scenario were:

Table 4. The Consolidation Model, Scenario 2 Results

(CONSOLIDATION SCENARIO 2)		95% C.I		
Identifier	Average	Half-width	Minimum	Maximum
Average Administrative Lead-Time	26.699	1.3452	23.408	29.075
Minimum Administrative Lead-Time	9.8565	0.78264	7.7212	12.576
Maximum Administrative Lead-Time	57.653	5.9592	46.975	74.039
Standard Deviation of Adm Lead-Time	9.8518	1.0608	7.3816	12.238

The last change included in this model was to let 50 percent of the orders go by mail and 50 percent over fax. This change gave the results seen in Table 5.

Table 5. The Consolidation Model, Scenario 3 Results

(CONSOLIDATION SCENARIO 3)		95% C.I		
Identifier	Average	Half-width	Minimum	Maximum
Average Administrative Lead-Time	24.407	0.5963	23.011	26.002
Minimum Administrative Lead-Time	8.0438	0.70104	6.4749	9.8086
Maximum Administrative Lead-Time	52.094	4.0781	44.172	66.061
Standard Deviation of Adm Lead-Time	9.1712	0.50303	8.0754	10.754

c. *Administrative lead-time (Electronic Commerce Model)*

The electronic commerce model is, as mentioned before, was built based on the description of possible use of electronic commerce at the Norwegian Navy Materiel Command. Which was discussed in Chapter V. Four different scenarios of the model were simulated.

The first scenario was presented in Section F, Sub-Section Four. Here, the process time at the item manager offices is unchanged. Further the payment process time is unchanged, and the model includes a electronic transfer time to vendors with a minimum of four and a half minute, a mode of 25 minutes and a maximum time of one day. Following results were obtained:

Table 6. The Electronic Commerce Model, Scenario 1 Results

(EC MODEL SCENARIO 1)		95% C.I		
Identifier	Average	Half-width	Minimum	Maximum
Average Administrative Lead-Time	21.03	0.92343	18.687	23.953
Minimum Administrative Lead-Time	5.6742	0.47591	4.0057	6.8096
Maximum Administrative Lead-Time	49.198	5.9256	38.452	66.326
Standard Deviation of Adm Lead-Time	9.2817	0.84423	7.5729	11.863

In the second scenario, the maximum process time at an item manager office was reduced from 30 days to 15 days. This change gave the results listed in Table 7.

Table 7. The Electronic Commerce Model, Scenario 2 Results

(EC MODEL SCENARIO 2)		95% C.I		
Identifier	Average	Half-width	Minimum	Maximum
Average Administrative Lead-Time	12.147	0.21746	11.238	12.749
Minimum Administrative Lead-Time	4.8094	0.22002	3.8468	5.4153
Maximum Administrative Lead-Time	22.477	0.71658	19.404	23.797
Standard Deviation of Adm Lead-Time	3.7876	0.15439	3.2662	4.0798

In the third scenario the payment process was changed to reflect a electronic payment process. The process time was simulated with a triangular distribution of minimum four and a half minute, a mode of about 15 minutes and a maximum of one day. The changes made in scenario one remained the same way. These changes gave following results:

Table 8. The Electronic Commerce Model, Scenario 3 Results

(EC MODEL SCENARIO 3)		95% C.I		
Identifier	Average	Half-width	Minimum	Maximum
Average Administrative Lead-Time	10.499	0.26381	9.2851	10.962
Minimum Administrative Lead-Time	3.4359	0.27921	2.6473	4.0966
Maximum Administrative Lead-Time	20.84	0.91465	18.536	23.696
Standard Deviation of Adm Lead-Time	3.7581	0.10187	3.4639	3.9654

In the last scenario, the payment process time and electronic transfer time were kept unchanged from last scenario. The item managers' maximum process time was further reduced to five days from 15 days. The final scenario produced therefore the results given in Table 9.

Table 9. The Electronic Commerce Model, Scenario 4 Results

(EC MODEL SCENARIO 4)		95% C.I		
Identifier	Average	Half-width	Minimum	Maximum
Average Administrative Lead-Time	7.3937	0.12299	6.8911	7.7366
Minimum Administrative Lead-Time	2.9017	0.33148	2.0778	3.7354
Maximum Administrative Lead-Time	12.828	0.46411	11.277	14.343
Standard Deviation of Adm Lead-Time	2.0435	0.05131	1.9399	2.1826

This concludes the results found on administrative lead-time based on the three models and their different scenarios.

I. SUMMARY

In this chapter simulation modeling as a tool for process redesign was introduced. The problem of classifying, designing/building and conducting the simulation of existing replenishment process of parts at the wholesale level of the Royal Norwegian Navy Materiel Command was described.

By using the process redesign approach described in Chapter IV a model where Procurement Department personnel were consolidated with personnel at the Logistics Division Internal Procurement Office was built.

Chapter V, Section E "Reengineering at the Materiel Command with Electronic Commerce", made the frame work for the electronic commerce model.

Further, animation of the simulation models was explained, and finally experienced administrative lead-time of each of the model scenarios was presented.

In the next chapter a comparative analysis of the different simulation results will be given.

VII. BENEFITS FROM REDESIGNING THE REPLENISHMENT PROCESS

A. INTRODUCTION

In this chapter, cost savings from changing existing replenishment process with either a consolidation of the two existing procurement environment, or through electronic commerce will be presented.

The presentation is based on simulation results given in Chapter VI, and further on comparison of these results in this chapter. Chapter VI, Section E, describes how the input variables in the simulation are based on probability distributions in order to mimic the randomness experienced in the real world. Random input induces randomness in the output. Therefore, 12 replications were run in order to gather a statistically significant data amount. By applying statistical analysis on the gathered data a true expected performance measure can with a high degree of confidence be estimated.

B. ANALYSIS OF SIMULATION RESULTS

In order to compare and analyze the results presented in previous chapter, the statistical theory applied to this thesis will in the following be briefly explained.

The main purpose of statistical analysis is to estimate or infer something concerning a large population by doing calculations with a sample from that population [Ref. 20]. In simulations it is often more convenient to think of sampling from some ongoing process (as the replenishment process) rather than from a static population. Underlying distributions govern the behavior of the process, and a sample is just a sequence of independent and identically distributed observations of the random variables.

In order to successfully apply statistical inference on gathered output data, the sample data (output) must according to statistical theory have been taken randomly [Ref. 28]. With the assumption that Arena's random-number generator is operating properly, it is fair to assume

that the random input makes random output, and hence the randomness of the sample is guaranteed.

1. Point Estimators and Confidence Intervals

Average, minimum and maximum administrative lead-time along with standard deviation were all presented as point estimators in Chapter VI. All point estimators have variability associated with them. Because of this, the point estimators will almost never hit exactly the correct value of the parameter they are estimating.

Confidence intervals are usually applied to the point estimator. The goal of a confidence-interval procedure is to form an interval with end points determined by the sample, that will contain the target parameter with a prespecified probability called the confidence level.

The usual notion is that the confidence level is $1-\alpha$, resulting in a $100\cdot(1-\alpha)$ percent confidence interval [Ref. 20]. In this thesis α is set to 0.05, which means a 95 percent confidence interval (95 % C.I.) is used. Thus with a confidence of 95 percent the parameter of interest lies between the calculated lower and upper limits of the interval.

As can be seen in Appendix B, C and D, confidence intervals on the mean average administrative lead-time and standard deviation of the lead-time respectively have been calculated for all scenarios of this thesis.

The formula used for confidence interval calculation on the mean is:

$$\overline{X} - \frac{t_{n-1,\alpha/2} \cdot S_x}{\sqrt{n}} < \mu < \overline{X} + \frac{t_{n-1,\alpha/2} \cdot S_x}{\sqrt{n}}, \tag{17}$$

where $t_{n-1,\alpha/2}$ is the, $1-\alpha/2$ quantile of the Student's t-distribution and the estimator for the population mean $\overline{X}$ is defined as:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} x_i . \tag{18}$$

Further, S_x, point estimator for standard deviation is defined as:

$$S_x = \sqrt{\frac{1}{n-1}\sum_{i-1}^{n}\left(X_i - \overline{X}\right)^2}. \qquad \textbf{(19)}$$

C. COMPARING THE SIMULATION RESULTS

In Table 10, the point estimates for each scenario regarding average lead-time, are listed.

Table 10. Average Administrative Lead-time All Scenarios

SCENARIO	AVERAGE
Existing System	28.9
Consolidation S1	26.3
Consolidation S2	26.7
Consolidation S3	24.4
EC Scenario 1	21
EC Scenario 2	12.1
EC Scenario 3	10.5
EC Scenario 4	7.39

The figure shows that the expected administrative lead-time falls from an average time consumed in today's system of 28.9 days to a possible shortest time of only 7.39 days for the last electronic commerce scenario. Further Appendix A, Section B, shows how the standard deviation varies between the different scenarios. Especially interesting here is the relationship between consolidation scenario one and two. The reason for this interest will be described in Sub-Section 2 of this section.

1. The Existing System

As explained in Chapter VI, Section E, Sub-Section 2, the existing system (base model) is based entirely on how the replenishment process works today. In other words the 95 percent confidence level on mean average administrative lead-time shown in Appendix B to fall between 28 and 30 days is a result of existing "business process".

2. The Consolidation Model

In the first scenario of the consolidation model, as described in Chapter VI, two out of five procurers at the Procurement Department are consolidated with the two existing procurers at the Internal Procurement Office. Further the mode process time at the Internal Procurement Office was increased from one day to two and a half day, which is 50 percent of the mode of the process time at the Procurement Department. Finally the maximum process time was increased from two and a half day to seven days, again 50 percent of existing Procurement department time. This extrapolation of process times from the existing replenishment process, are assumed reasonable and may indeed be very conservative.

By using the statistical tools explained in Section B of this chapter, and assuming that the process times reflect what would have happened if the redesign proposal was implemented, it is found that with 95 percent confidence the mean average administrative lead-time now will be reduced to between 25.4 days and 27.2 days (see Appendix C, Section D). The standard deviation, however, did increase to at 95 percent confidence level, between 0.9 and 2.05 days.

The confidence intervals for the existing system and this first scenario of the consolidation proposal does not intersect. This means that a consolidation of the Procurement Department and the Internal Procurement Office, will with a very high certainty reduce administrative lead-time.

In the second scenario of this model (proposal), when the maximum internal procurement process time was reduced, we expected that the administrative lead-time would reduce. This did not happen, instead the average lead-time went up from 26.303 days to 26.609 days. However, the confidence interval did also increase from a 0.95 half width interval of 0.846 to 1.345 (see Appendix C). This indicated that the population mean of the two scenarios might be the same, and therefore a hypotheses test with:

$$H_0 = \text{ Means are equal } (\mu = \mu_0)$$

and

$$H_1 = \text{ Means are equal } (\mu \neq \mu_0)$$

was conducted (see Appendix C, Section F). The decision ruled used was:

$$\text{Reject } H_0 \text{ if}$$

$$\frac{\bar{x}\text{-}\mu_0}{s/\sqrt{n}} > t_{n-1,\alpha/2}$$

or

$$\frac{\bar{x}\text{-}\mu_0}{s/\sqrt{n}} > -t_{n-1,\alpha/2}$$

This paired - T means comparison was done through Arena output analyzer. The comparison failed to reject H_0, which means that the population means of the two scenarios are equal at the 0.05 level (see Appendix C, Section F).

The third scenario indicated that the mailing process versus use of fax will have an impact on average administrative lead-time. In this scenario it was assumed that the number of orders sent by fax can be increased from 20 percent to 50 percent of total number of orders. For this scenario the confidence interval on average lead-time did not cover any of the two proceeding scenarios (see Appendix C, Section D), and the standard deviation was clearly more narrow than that of scenario one and two (2.68 compared to 4.98 and 4.86 respectively, see Appendix C, Section E).

From this analysis of the first redesign proposal, it can be concluded that by consolidating the two procurement offices, some benefit in form of reduced administrative lead-time will be gained compared to existing system. The study further shows that the means of transportation of orders to the different vendors (mail versus fax) may have larger impact on administrative lead-time. The importance of streamlining the way of transporting information (orders) is the main purpose of the practice presented through the next redesign proposal, namely electronic commerce.

3. The Electronic Commerce Model

In the first scenario of this last redesign effort, ordering is assumed done electronically the way explained in Chapter V of this thesis. The time to process proposals for replenishment was in Chapter V, Section E described as becoming a lot shorter than with a non-electronic commerce system. In the first scenario however, the proposal process time was set very conservative in order to estimate the effect of now longer having to use mail and/or fax to transport orders.

Appendix D, Section D shows that estimated mean average lead-time now is 21 days with a 95 percent confidence interval from 20.04 days to 21.96 days. Even if the standard deviation is a little higher than for the existing system (1.38 days compared to 0.634 days), this is clearly better than the 29 day average administrative lead-time found on the base model. Since proposal processing time is the same, most of the reduction in lead-time is due to no longer having to use mail or fax.

Referring to other organizations experience with electronic commerce as a mean for substantial reductions in order processing time (see Chapter V, Section C), it was, in scenario two, assumed that it no longer was necessary for the item manager to use as much as 30 days (maximum in the underlying triangular proposal processing time), and hence the maximum time was reduced to 15 days.

As can be seen in Appendix D, this will have a large impact on estimated mean average lead-time, which now is reduced to 12 days with a very small standard deviation of 0.252 days.

In scenario three, again using the findings from Chapter V as background, electronic payment was included in the model. Most companies that start with electronic commerce also include electronic payment as part of the "package", instead of the old manual way of paying. Again it was found that lead-time was reduced. This time however, the reduction is smaller, from 12 days to 10.5 days. But since the confidence interval does not intersect with last scenarios confidence interval, and the standard deviation is reduced (see Appendix D) it is reasonable to believe that this is a real reduction in administrative lead-time.

As a last effort in this thesis to do a sensitivity analysis on order/proposal processing time at the item manager offices, the maximum processing time in this triangular distribution was reduced to five days, This scenarios results confirm that the more narrow the input (process time) distribution becomes, the less will the output variable in question, namely administrative lead-time become. The mean average lead-time was now 7.4 days compared to last scenario's 10.5 days. In other words, by reducing input process time's upper limit with two days, a total lead-time reduction of three days was experienced.

4. Summary

The simulation results clearly show that administrative lead-time experienced in existing system is long and can be reduced. A reduction can be obtained through a consolidation of the two procurement procedures involved in the existing replenishment process, but this reduction was not significant. With traditional means of conducting replenishment (no electronic commerce), a clear strategy of using fax instead of the mail system might actually give a larger reduction in administrative lead-time.

The real possibility for reduction in lead-time is found within the use of electronic practices. The further this area is exploited, the larger potential for reduction in lead-time. At any rate a very important part in the pursue of reduced administrative lead-time will be within the control and stress on reduction of variability in all process times.

D. COST AND SAVINGS POTENTIALS

In this section estimates of costs and savings from the two redesign efforts will be given.

1. Consolidation

The cost to consolidate two out of five procurers at the Procurement Division, with the two existing procurers at the Logistics Division's Internal Procurement Office is not very high. One problem known to be existent at the Logistics Division, is lack of office space at the Division's main building. It is very important to locate the Internal Procurement Office in the same building with the item managers for the benefits from consolidation to be realized.

Another question not addressed in this thesis, is possible organizational and union resistance to a change of existing organizational structures.

If however, assuming that the consolidation can be done, it has been shown through the simulation that the replenishment process can be handled by four procurers compared to today's seven. Excess personnel might be needed elsewhere in the Materiel Command's organization. For the replenishment process however, this means a reduction of Norwegian Kroner (NOK) 750,000 (this is about US $ 107,142), in annual personnel cost including benefits.

As mentioned in Chapter III, Section E a research into the Norwegian Navy Materiel Command's inventory database was conducted in association with this thesis. Summary of the research was limited to the C-model, which is the model that generate automatically calculated safety stock need (A sample of the summary of the C-model can be seen in Appendix E). Since safety stock is incorporated in reorder point (R), an exact figure for the safety stock value was not possible to find from this research. In other words, a separate file for R is not kept in the database.

The total number of stock keeping units (SKU) within the C-model was found to be 4,159 (per 1 October 1997). This is actually only three percent of a total number of different SKUs of 135,000 in the Materiel Command's inventory. Further the total reorder point sum over all C-model SKUs was found to be 243,533 items. This will give an average reorder point (R) for all 4,159 stock keeping units of:

$$\text{Average } R = \frac{243{,}533}{4{,}1.59} \approx 59 .$$

To find the average price to be used in calculation of safety stock value, the total C-model inventory value of NOK 64,244,937 was divided by the number of items on hand, which was 1,493,861 (See Appendix E).

$$\text{Average item price } \frac{64{,}244{,}937}{1{,}493{,}861} \approx 43 .$$

Chapter III, Section C showed that the safety stock (*SS*) in the C-model is calculated in the following way:

$$SS = SAFA \times MAD_L .$$

It was further shown that SAFA (Safety-Factor) was based on a so called service function (SEFU):

$$SEFU = Q/_{MAD_L} \times (1-k) .$$

Where Q is the order quantity, set to three-month demand. However, no more is known about demand for each SKU in the C-model, than what is the requirements for the SKU to be in the model in the first place. In Chapter III it was explained that to be in the C-model, the demand over the last 12 months had to equal or be greater than 10 units and demand forecast for the next period has to be equal to or grater than three units.

It was also found in Chapter III, that the safety factor SAFA, can be between zero and three. In order to have an estimate of SAFA to be used to estimate safety stock for evaluation of SAVINGS POTENTIAL, it was assumed that over all items within the C-model SAFA will be one and a half. The next value needed to estimate total safety stock in the C-model, is mean absolute deviation (MAD). The sum over all items within the C-model was found from the inventory database to be 109,138 (see Appendix E).

Total safety stock of the C-model is on this bases estimated to be:

$$SS = (1.5)(109{,}138) = 163{,}707 .$$

The research into the inventory database revealed, as mentioned above, a total value of the C-model of NOK 64,244,937. With an average price per item of NOK 43, total value of safety stock will be NOK 7,039,401. In other words, only a little over 10 percent of total inventory value. This confirms the belief of safety stock value not being overestimated in this thesis.

By applying a holding cost rate of 23 percent (US Navy's holding rate on consumables), the yearly holding cost of safety stock under the C-model is NOK (7,039,401*0.23) = NOK 1,619,062 or about US $ 231,295.

The simulation results show that with a good implementation of the consolidation replenishment proposal, a reduction in administrative lead-time of about five days can be realized (from 29 days down to 24 days). This is a reduction of about 17 percent. This will not necessarily mean a reduction in safety stock of 17 percent, but 10 percent reduction in safety stock would not be an overestimate. With this assumption, a new safety stock will then be about 147,300 with a new yearly holding cost of NOK 1,456,797, i.e. a saving of NOK 162,265.

There will also be savings in manually calculated safety stock within the A-model and the B-model. These savings can even be much higher than the savings found within the C-model, because the C-model has only about three percent of the total number of stock keeping units. Savings from the A-model and B-model are, however, very hard to quantify, and are therefore not included. To sum up, the estimated quantifiable total yearly SAVINGS POTENTIAL for the consolidation proposal is:

Table 11. Savings potential Consolidation Model

PERSONNEL	NOK 750,000
Holding Cost Safety Stock	NOK 163,000
Total	NOK 913,000 ($ 130,430)

The holding cost of safety stock includes; costs of capital, obsolescence and storage. Because of this, the only cost that will be registered as "real" reduction on budget spending is not necessarily equal to this calculated total cost. Further the saving in personnel cost for the Materiel Command as a whole, will depend on whether the assumed reduction in needed personnel are reflected in a cut in total number of Materiel Command personnel or not.

2. Electronic Commerce

It is not within the scope of this thesis to make a thorough research on the cost of implementing electronic commerce at the Norwegian Navy Materiel Command. However research on the world wide web showed that the price of an electronic commerce system can vary from a rather low cost system with limited performance, to very expensive systems that

fully integrates electronic practices with inventory control, inventory management, distribution and so on.

In the low price range, IBM has, for example, an electronic commerce system that will let the user organization apply business to business commerce over the Internet at a starting price (per 1 November 1997) of $ 4,995 [Ref. 29]. On the other hand it is fully possible to procure integrated systems in the multi-million dollar class.

Since the method used in this thesis to quantify savings potential, was presented in last sub-section, this sub-section will simply present the possible quantifiable savings due to use of electronic commerce.

For calculation purpose the assumption is that electronic commerce has made possible the largest reduction shown through the simulation scenarios of the electronic commerce model (See Chapter VI). The result on administrative lead-time in the last scenario of this model was a reduction from the existing system time of 29 days down to seven days. This is in other words a reduction of 75 percent.

As in the last sub-section it is not assumed that this means 75 percent reduction in safety stock need, but an assumption of 50 percent reduction should not be far off.

Existing yearly holding cost was estimated to be NOK 1,619,062. With a 50 percent reduction in safety stock need, this will mean that the safety stock holding cost saving is NOK 809,500.

Further this model assumed that dedicated procurement personnel was no longer needed in the replenishment of stored items, instead the item managers themselves did the ordering. In the existing system, total number of personnel involved in the replenishment process are seven. It is assumed however, that the Materiel Command may want to keep two of the positions for other contracting purposes or for establishing blanket contacts[3] with vendors. With this assumption made, a yearly savings potential of five positions is used in the

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[3] A blanket order is a contract to purchase certain items from the vendor. It is not an authorization to ship anything. Shipment is made only upon receipt of an agreed-upon document, perhaps a shipping requisition or shipment release etc. [Ref. 18 P. 539]

analysis. On the basis of same cost per person as given in last sub-section, the savings potential is NOK 1,250,000.

Chapter III, Section E showed that on-hand inventory under the C-model alone was 255,672 items above maximum inventory level calculated by the inventory control system. With the average price of NOK 43 found in last sub-section used, this mean an excess inventory valued at NOK 10,993,896. If use of electronic commerce could make the item managers no longer "over buy" in order to protect against variability, this would mean a calculated saving in holding of excess stock within the C-model alone of (10,993,896*0.23) NOK 2,528,596.

Besides this quantifiable savings, possible savings from the other models, the A-model and the B-model, and elimination/reduction in mailing cost, paper cost and so on might even be bigger than what is quantified in this thesis. To sum up the electronic commerce proposal, the quantifiable savings potential from this proposal is:

Table 12. Savings potential Electronic Commerce Model

HOLDING COST SAFETY STOCK	NOK 809,000
Personnel	NOK 1,250,000
Holding Cost "Excess" inventory	NOK 2,528,596
Total	NOK 4,588,096 (US $ 655,442)

Notice that the reservations on calculated cost, and use of excess personnel given in the analysis of the consolidation proposal's savings potentials, is also applicable to this proposal.

VIII. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary of the research, major conclusions and recommendations for further research.

A. RESEARCH QUESTION NUMBER ONE

The first research question of this thesis was to find what impact lead-time has on service level and cost, within a theoretical inventory control frame. This was done in Chapter II through study of inventory control theory and presentation of basic inventory control models. The research was restricted to traditional economic order quantity models, where the main purpose is to reduce overall cost. It was stated that these models may conflict with the Navy's goal of maximizing operational readiness. In spite of this, modified classic inventory models are still used in both the US Navy and the Norwegian Navy, and this is why the basic inventory models were presented.

It was shown that since the future demand for an item is uncertain (stochastic), and vary over time, organizations/businesses keep in most cases some safety stock. If demand is highly variable it becomes harder to obtain a predetermined level of service. Thus in order to have an inventory level that can make sure that the predetermined service level is met at a minimum cost, mathematical calculation of reorder point and safety stock is needed.

In the Navy, not only demand for an item will vary over time, but the replenishment time of inventory will also vary. Hence, it becomes even more difficult to obtain the predetermined service level.

It was shown both mathematically and graphically, that the cost in form of safety stock holding cost, will be far higher with variability in lead-time, than if lead-time is known and constant.

One major conclusion was that when both lead-time demand and lead-time itself vary, an organization with a predetermined service goal must take the total variance into account. An assumption of no variability in lead-time will in such a scenario be almost a guarantee against

reaching the predetermined service level. Further a reduction in lead-time will have a much higher impact on cost in a system where both lead-time demand and lead-time itself vary, than in a system with known and constant lead-time, given that the first system protect against all variability.

B. RESEARCH QUESTION TWO

The second research question was to present current inventory control policy at the Norwegian Navy Materiel Command. This was done in Chapter III. The research findings were based on communication with Materiel Command personnel and further on data received from the Command.

It was found that the inventory control policy used is a version of the basic Min-Max Continuous Review Model presented in Chapter II. It was shown how inventory items are separated into three main handling categories. Further, only those items that have a relatively high historical - and forecasted - demand are fully handled by the computerized inventory control system.

The Materiel Command's original intent was that the vast majority of inventory items should be handled by the fully automated computer system (the C-model). It was therefore surprising to find through this research that only about three percent of the different stock keeping units accounted for at the Command, currently are controlled under this category. This finding, together with the fact that the A-model and B-model give the item managers, at least perceived, grater flexibility in their inventory management, further imply that classic inventory control models are far from optimal in military inventory control and management.

In the Materiel Command's C-model, lead-time was found to be a running average of the two last replenishment lead-times. Further, no protection against variability in lead-time itself, is included in the model. The conclusion drawn from this fact, is that the C-model has less protection against stock-out than the theoretical model presented in Chapter II. It was also found that automated savings in form of reduced holding cost of safety stock, due to reduced administrative lead-time, is less in the C-model than in the theoretical model. However, even

without protection against lead-time variability, a reduction in lead-time will induce reduced variability and hence reduce the probability of stock-outs.

The last major finding associated with research question two, was only touched very briefly because it was beyond the scope of this thesis. The Norwegian Navy does not use an economic order quantity, but basically orders three months forecasted demand. It was shown that this would most likely yield higher inventory management cost, than what use of modified economic order quantity would.

C. RESEARCH QUESTION THREE

Research question three was to establish basic knowledge about business process reengineering and electronic commerce, in order to use this as a framework on the proposed redesign of current replenishment process at the Materiel Command.

The first part of the research question was answered in Chapter IV. It was found that business process reengineering can be difficult to apply on processes, because many process has not been engineered in the first place. Instead they have simply emerged over years of business. However, it was found that it might be possible to engineer and reengineer a process simultaneously. This process, often called process redesign, was chosen as the business process redesign approach used in this thesis.

The redesign process was as follows: The first step was to establish a vision/goal, which in this case was to reduce administrative lead-time. Then the current process was identified in cooperation with the Norwegian Navy Materiel Command. Current replenishment process was further built as a simulation model that measures administrative lead-time. Then the two new approaches to the current process were introduced, and finally these processes were measured and evaluated against current replenishment process.

The second part of research question three, was to introduce electronic commerce. Electronic commerce was one of the two new approaches to current replenishment process. In Chapter V, it was explained what electronic commerce really is. More specifically electronic commerce over the Internet was in focus.

It was shown in this chapter that electronic commerce is a driving force in today's business environment, and that is also has a growing importance within the public sector. Real life success stories show that electronic commerce can reduce lead-times considerably, and therefor, also reduce variability within a replenishment process.

The main conclusion is that what has been seen of electronic commerce so far, is just the beginning. The possibilities within this field are almost unlimited, and it is highly recommended that the Norwegian Navy Materiel Command start looking more at electronic commerce as a mean to conduct business now, and in the very near future.

D. RESEARCH QUESTION FOUR

Research question four was to investigate if it is possible to reduce administrative lead-time, and how much can it be reduced through:

- Consolidation of existing procurement environments involved in the replenishment of inventory items, and;
- Introduction and use of electronic commerce.

This fourth research question was answered in Chapter VI. Computer simulation was introduced, and used as a tool to answer the question. Three main computer models, were built. The first model simulated existing replenishment process, in order to establish existing administrative lead-time. This lead-time was validated against, the information obtained from the Materiel Command.

The following two models, and their different scenarios, modeled and simulated the consolidation proposal and electronic commerce proposal respectively. These models were built in accordance with the frame-work established in Chapter IV and Chapter V of this thesis.

The main conclusion was that both redesign proposals will reduce the administrative lead-time experience through the replenishment of inventory items to the Norwegian Navy Materiel Command. It was also concluded that the largest reduction can be achieved through an introduction and use of electronic commerce.

E. RESEARCH QUESTION FIVE

The last research question was to find what benefits can be gained at the Navy Materiel Command from introducing one of the redesign proposals.

To answer this question, the results of the simulation conducted on the two redesign proposals in Chapter VI were evaluated and compared. Further the cost of each proposal was assessed. The conclusion was that the consolidation proposal can be done at a relative low cost, but not necessarily without organizational challenges. Cost of the electronic commerce proposal is far more uncertain. Cost in this case was shown to really depend on requirement placed on the system. Yet the cost of electronic commerce will go down as technology matures.

The savings potential of both proposals could only partially be quantified. Hence it is therefore important to notice that the benefits from each of the two proposals are expected to be greater than what this thesis' quantifiable figures could indicate. It was also pointed out that in this research, calculated cost savings are not separated from "real" cost savings. This means that the total savings indicated in the thesis, can not be assumed directly transferable to budget spending reductions.

The main conclusion was that the electronic commerce proposal will generate at least four times as large savings as the consolidations proposal. Notice that this is without considering cost of each of the proposals.

The main recommendation is that the Norwegian Navy Materiel Command strongly consider using electronic commerce in the replenishment of items held in their inventory.

F. RECOMMENDATIONS FOR FURTHER RESEARCH

During this research several areas for further research became evident. These areas include:

- Is it possible and/or desirable to introduce protection against variability in lead-time itself along with protection against lead-time demand variability in the Norwegian Navy's inventory control policy?

- Would it be better to use economic order quantity (EOQ), instead of the three months forecasted demand used currently as replenishment quantity?

- Why is only about three percent of total number of different stock keeping units (SKU) currently controlled be the C-model? Does this mean that current inventory control model has failed?

- Should the Norwegian Navy Materiel Command consider use of for example a readiness based sparing (RBS) model, instead of today's basic Min-Max inventory control model?

- Will it be organizational possible to change from today's manually oriented inventory management processes, to a highly electronic oriented system? If so, how fast can it be done?

- Can electronic practices be used to reduce cost in other logistics areas than replenishment of inventory items?

- Can use of computer simulations help streamline the total logistics area of the Norwegian Navy? If so, how can this be done?

APPENDIX A. COMPARISON OF ALL SIMULATION SCENARIOS

A. MINIMUM, MAXIMUM AND AVERAGE ADMINISTRATIVE LEAD-TIME

Table A.1 Average Lead-Times over 12 Replications; All Scenarios

	MINIMUM	AVERAGE	MAXIMUM
Existing System	9.03	28.9	57.6
Consolidation S1	9.52	26.3	55.9
Consolidation S2	9.86	26.7	57.7
Consolidation S3	8.04	24.4	52.1
EC Scenario 1	5.67	21	49.2
EC Scenario 2	4.81	12.1	22.5
EC Scenario 3	3.44	10.5	20.8
EC Scenario 4	2.9	7.39	12.8

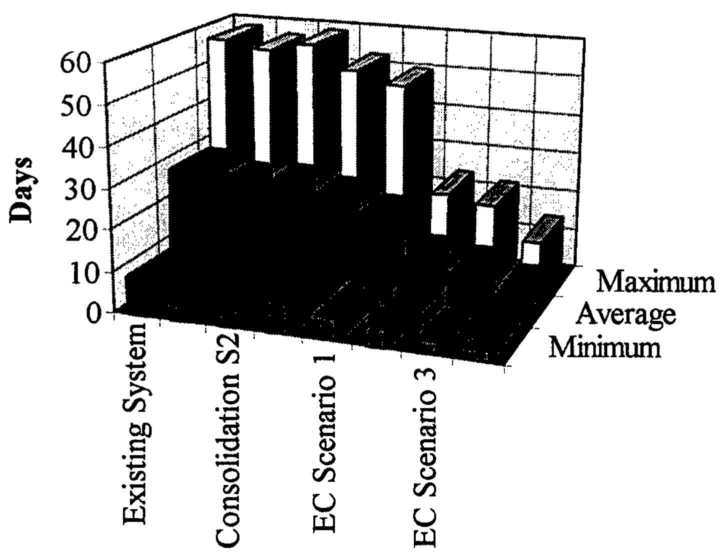

Figure A.1 Lead-Times all Scenarios

B. STANDARD DEVIATION OF ADMINISTRATIVE LEAD-TIME

Table A.2 Standard Deviation of Administrative Lead-Time

	STANDARD DEVIATION
Existing System	0.634
Consolidation S1	1.21
Consolidation S2	1.73
Consolidation S3	0.822
EC Scenario 1	1.38
EC Scenario 2	0.252
EC Scenario 3	0.166
EC Scenario 4	0.0838

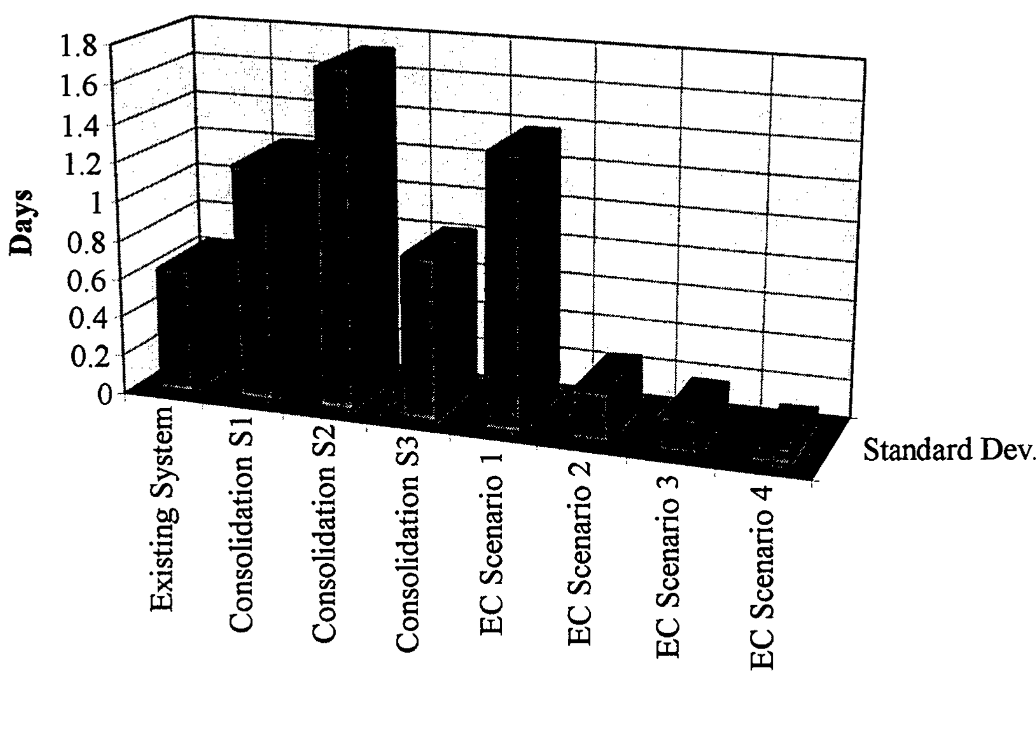

Figure A.2 Standard Deviation Compared over All Scenarios

APPENDIX B. EXSISTING (BASE) SYSTEM RESULTS

A. SUMMARY

Table B.1 Base Model Results

(BASE MODEL)		**95% C.I**		
Identifier	**Average**	**Half-width**	**Minimum**	**Maximum**
Average Administrative Lead-Time	28.943	0.70852	27.034	30.968
Minimum Administrative Lead-Time	9.0279	0.96559	5.7426	11.209
Maximum Administrative Lead-Time	57.629	3.3765	47.929	69.951
Standard Deviation of Adm Lead-Time	10.223	0.38828	9.2891	11.654

B. AVERAGE ADMINISTRATIVE LEAD-TIME, ALL REPLICATIONS

Table B.2 Mean Average Lead-Time over 12 Replications

REPLICATION	AVG. ADM LEAD-TIME
1	27.034
2	28.899
3	28.373
4	28.793
5	30.968
6	29.346
7	28.564
8	27.352
9	30.785
10	29.439
11	28.595
12	29.168

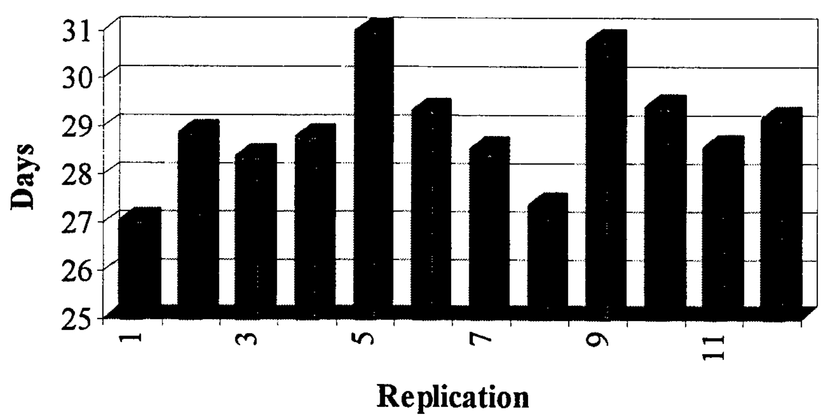

Figure B.1 Average Administrative Lead-Time per Replication

C. 95 PERCENT CONFIDENCE INTERVAL ON MEAN AVERAGE ADMINISTRATIVE LEAD-TIME

Table B.3 C.I. Administrative Lead-Time Base System

IDENTIFIER	AVERAGE	LOWER	UPPER	MINIMUM	MAXIMUM
	lead-time	**0.95 C.I**	**0.95 C.I**	**lead-time**	**lead-time**
Existing System	28.9	28.164	29.636	27	31

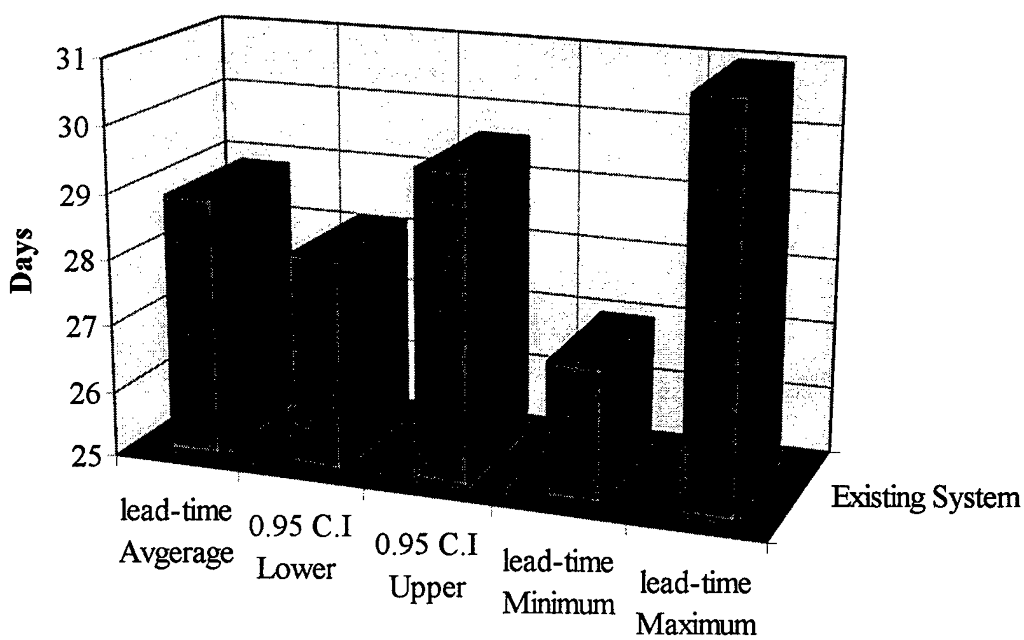

Figure B.2 Confidence Interval Mean Lead-Time Base System

D. 95 PERCENT CONFIDENCE INTERVAL ON STANDARD DEVIATION OF ADMINISTRATIVE LEAD-TIME

Table B.4 Confidence Interval on Base System Standard Deviation

IDENTIFIER	LOWER 0.95	ESTIMATED	UPPER 0.95	RANGE
	C.I. Limit	Std. Deviation	C.I. Limit	
Existing System	0.449	0.634	1.08	2.37

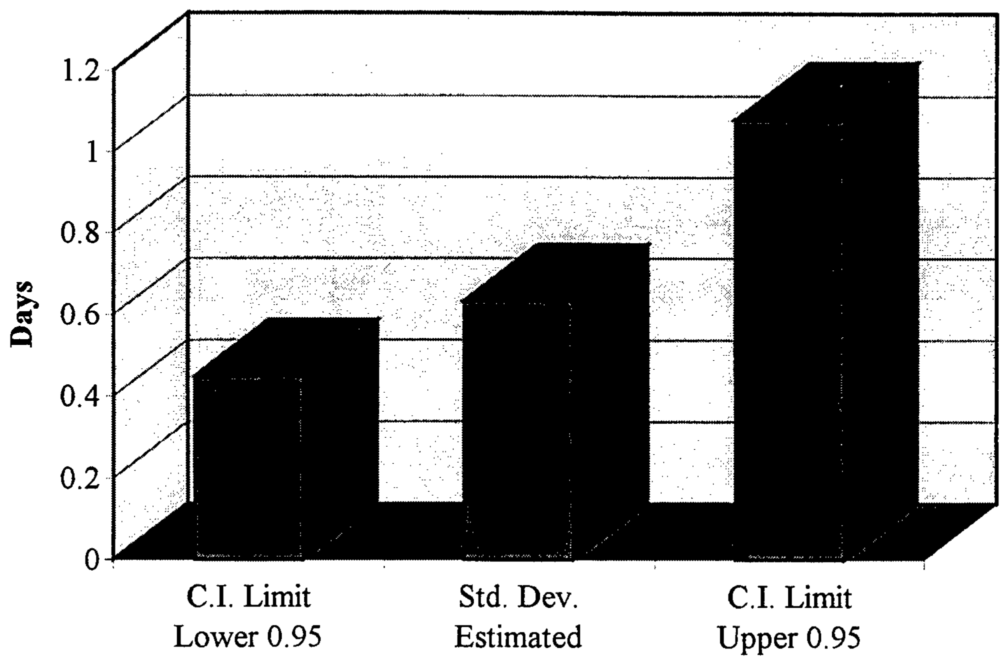

Figure B.3 95 Percent Confidence Interval on Standard Deviation Existing System

E. SAMPLE OUTPUT DATA FROM ARENA, BASE SYSTEM

ARENA Simulation Results

Bernt E. Tysseland - License #9400000

Summary for Replication 12 of 12

Project: Replenishment at — Run execution date : 11/ 5/1997

Analyst: LCDR Bernt E Tys — Model revision date: 11/ 5/1997

Replication ended at time : 4382.0

Statistics were cleared at time: 4017.0

Statistics accumulated for time: 365.0

TALLY VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Observations
Depart 1_Ta	29.168	(Insuf)	9.7775	55.060	155
Enter supply system_R_	.01105	(Insuf)	.00000	.84783	157
Paying_R_Q Queue Time	.00000	(Insuf)	.00000	.00000	157
Electronics_R_Q Queue	3.8961	(Insuf)	.00000	17.992	26
Weapon parts office_R_	.74765	(Insuf)	.00000	8.0971	27
POL_R_Q Queue Time	4.5788	(Insuf)	.00000	20.845	27
Navigation_R_Q Queue T	5.3899	(Insuf)	.00000	17.559	26
Receiving department_R	.00998	(Insuf)	.00000	.87408	155
Internal procurement_R	.00000	(Insuf)	.00000	.00000	57
Procurement_R_Q Queue	.00000	(Insuf)	.00000	.00000	99
General Supply_R_Q Que	3.3277	(Insuf)	.00000	13.024	27
Hull and Ship Parts_R_	2.4111	(Insuf)	.00000	20.484	27

DISCRETE-CHANGE VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Final Value
# in Receiving departm	.00424	(Insuf)	.00000	1.0000	.00000
Procurement_R Availabl	5.0000	(Insuf)	5.0000	5.0000	5.0000
# in Paying_R_Q	.00000	(Insuf)	.00000	.00000	.00000
Paying_R Busy	.86077	(Insuf)	.00000	4.0000	1.0000
Enter supply system_R	3.0000	(Insuf)	3.0000	3.0000	3.0000
Internal procurement_R	.18825	(Insuf)	.00000	2.0000	.00000
# in General Supply_R_	.24616	(Insuf)	.00000	1.0000	.00000
# in Procurement_R_Q	.00000	(Insuf)	.00000	.00000	.00000

Electronics_R Availabl	1.0000	(Insuf)	1.0000	1.0000	1.0000
Navigation_R Available	1.0000	(Insuf)	1.0000	1.0000	1.0000
# in Navigation_R_Q	.38394	(Insuf)	.00000	2.0000	1.0000
Hull and Ship Parts_R	1.0000	(Insuf)	1.0000	1.0000	1.0000
# in Hull and Ship Par	.17836	(Insuf)	.00000	2.0000	.00000
Weapon parts office_R	1.0000	(Insuf)	1.0000	1.0000	1.0000
# in Weapon parts offi	.05531	(Insuf)	.00000	1.0000	.00000
Receiving department_R	3.0000	(Insuf)	3.0000	3.0000	3.0000
Navigation_R Busy	.79897	(Insuf)	.00000	1.0000	1.0000
Enter supply system_R	.90443	(Insuf)	.00000	3.0000	3.0000
# in Internal procurem	.00000	(Insuf)	.00000	.00000	.00000
General Supply_R Busy	.74160	(Insuf)	.00000	1.0000	1.0000
# in POL_R_Q	.33871	(Insuf)	.00000	2.0000	.00000
Receiving department_R	.86301	(Insuf)	.00000	3.0000	1.0000
Procurement_R Busy	1.7599	(Insuf)	.00000	5.0000	1.0000
Hull and Ship Parts_R	.67268	(Insuf)	.00000	1.0000	1.0000
# in Electronics_R_Q	.27754	(Insuf)	.00000	2.0000	1.0000
Weapon parts office_R	.50767	(Insuf)	.00000	1.0000	1.0000
POL_R Busy	.65720	(Insuf)	.00000	1.0000	1.0000
Paying_R Available	5.0000	(Insuf)	5.0000	5.0000	5.0000
Electronics_R Busy	.80130	(Insuf)	.00000	1.0000	1.0000
General Supply_R Avail	1.0000	(Insuf)	1.0000	1.0000	1.0000
POL_R Available	1.0000	(Insuf)	1.0000	1.0000	1.0000
# in Enter supply syst	.00476	(Insuf)	.00000	1.0000	.00000
Internal procurement_R	2.0000	(Insuf)	2.0000	2.0000	2.0000

COUNTERS

Identifier	Count	Limit
Navigation_C	25	Infinite
Weapon parts office_C	27	Infinite
Receiving department_C	157	Infinite
Procurement_C	99	Infinite
General Supply_C	26	Infinite
Paying_C	156	Infinite
Electronics_C	26	Infinite
Internal procurement_C	57	Infinite
Hull and Ship Parts_C	26	Infinite
Depart 1_C	155	Infinite
Enter supply system_C	155	Infinite
POL_C	26	Infinite

OUTPUTS

Identifier	Value
Avg Delay Time at Gene	3.3277
Minimum Adm Lead Time	9.7775
Avg Delay Weapon Off B	.74765
Avg Delay at Procur De	.00000
Avg Adm Lead Time Base	29.168
Avg Delay at Receiving	.00998
StdD Adm Lead Time Bas	9.8394
Avg Delay to Enter int	.01105
Max Adm Lead Time Base	55.060
Avg Delay at POL Offic	4.5788
Avg Delay Hull and Ski	2.4111
Avg Delay at Internal	.00000
Avg Delay at Paying Of	.00000
Number of Completed Re	155.00
Avg Delay at Navigatio	5.3899
Avg Delay at Electroni	3.8961

ARENA Simulation Results

Bernt E. Tysseland - License #9400000

Output Summary for 12 Replications

Project: Replenishment at   Run execution date : 11/ 5/1997

Analyst: LCDR Bernt E Tys   Model revision date: 11/ 5/1997

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Avg Delay Time at Gene	3.0241	1.3581	1.1818	8.5392	12
Minimum Adm Lead Time	9.0279	.96559	5.7426	11.209	12
Avg Delay Weapon Off B	3.6867	1.4035	.63718	7.7853	12
Avg Delay at Procur De	.01108	.01006	.00000	.04932	12
Avg Adm Lead Time Base	28.943	.70852	27.034	30.968	12
Avg Delay at Receiving	.02841	.00859	.00683	.05255	12
StdD Adm Lead Time Bas	10.223	.38828	9.2891	11.654	12
Avg Delay to Enter int	.03290	.01183	.01105	.06615	12
Max Adm Lead Time Base	57.629	3.3765	47.929	69.951	12
Avg Delay at POL Offic	3.0888	1.0908	.89875	6.5671	12

Avg Delay Hull and Ski	3.5699	1.3336	1.4013	9.4744	12
Avg Delay at Internal	.00381	.00354	.00000	.01424	12
Avg Delay at Paying Of	3.2440E-04	6.8772E-04	.00000	.00389	12
Number of Completed Re	155.58	1.7003	149.00	159.00	12
Avg Delay at Navigatio	3.4806	.96205	1.1138	5.9759	12
Avg Delay at Electroni	3.3257	1.2047	.41330	7.5315	12

Simulation run time: 0.72 minutes.

Simulation run complete.

APPENDIX C. CONSOLIDATION MODEL RESULTS

A. ANIMATED CONSOLIDATION MODEL

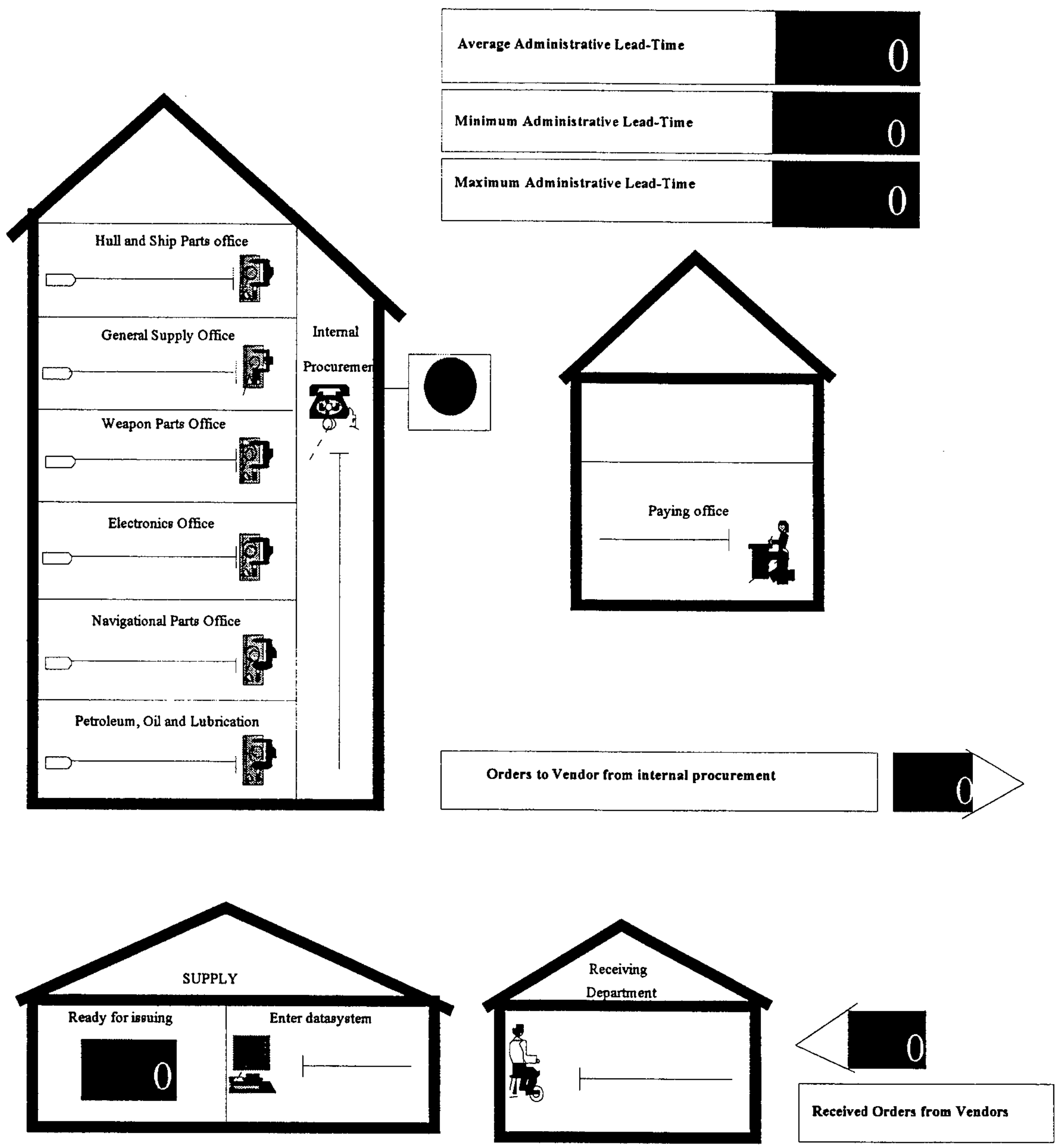

Figure C.1 Picture of Arena Animated Consolidation Model (Scenario 1)

B. CONSOLIDATION SCENARIO RESULTS SUMMARY

Table C.1 The Consolidation Model, Scenario 1 Results

(CONSOLIDATION SCENARIO 1)		95% C.I		
Identifier	**Average**	**Half-width**	**Minimum**	**Maximum**
Average Administrative Lead-Time	26.303	0.84575	24.197	28.534
Minimum Administrative Lead-Time	9.5212	0.98056	6.081	12.106
Maximum Administrtive Lead-Time	55.892	4.3984	44.404	67.872
Standard Deviation of Adm Lead-Time	9.3088	0.73858	6.8663	11.843

Table C.2 The Consolidation Model, Scenario 2 Results

(CONSOLIDATION SCENARIO 2)		95% C.I		
Identifier	**Average**	**Half-width**	**Minimum**	**Maximum**
Average Administrative Lead-Time	26.699	1.3452	23.408	29.075
Minimum Administrative Lead-Time	9.8565	0.78264	7.7212	12.576
Maximum Administrtive Lead-Time	57.653	5.9592	46.975	74.039
Standard Deviation of Adm Lead-Time	9.8518	1.0608	7.3816	12.238

Table C.3 The Consolidation Model, Scenario 3 Results

(CONSOLIDATION SCENARIO 3)		95% C.I		
Identifier	**Average**	**Half-width**	**Minimum**	**Maximum**
Average Administrative Lead-Time	24.407	0.5963	23.011	26.002
Minimum Administrative Lead-Time	8.0438	0.70104	6.4749	9.8086
Maximum Administrative Lead-Time	52.094	4.0781	44.172	66.061
Standard Deviation of Adm Lead-Time	9.1712	0.50303	8.0754	10.754

C. AVERAGE ADMINISTRATIVE LEAD-TIME, ALL CONSOLIDATION SCENARIOS OVER 12 REPLICATIONS

Table C.4 Average Administrative Lead-Time all Scenarios, 12 Replications

REPLICAT.	CONSOL. S 1	CONSOL. S 2	CONSOL. S 3
1	26.5	23.538	25.042
2	26.273	25.023	23.011
3	26.722	23.408	23.082
4	24.197	24.523	25.365
5	25.111	25.103	23.459
6	27.277	27.907	26.002
7	28.534	28.978	23.78
8	24.651	28.448	24.507
9	28.449	28.678	24.052
10	25.631	29.075	24.13
11	26.207	27.469	25.109
12	27.083	28.237	25.344

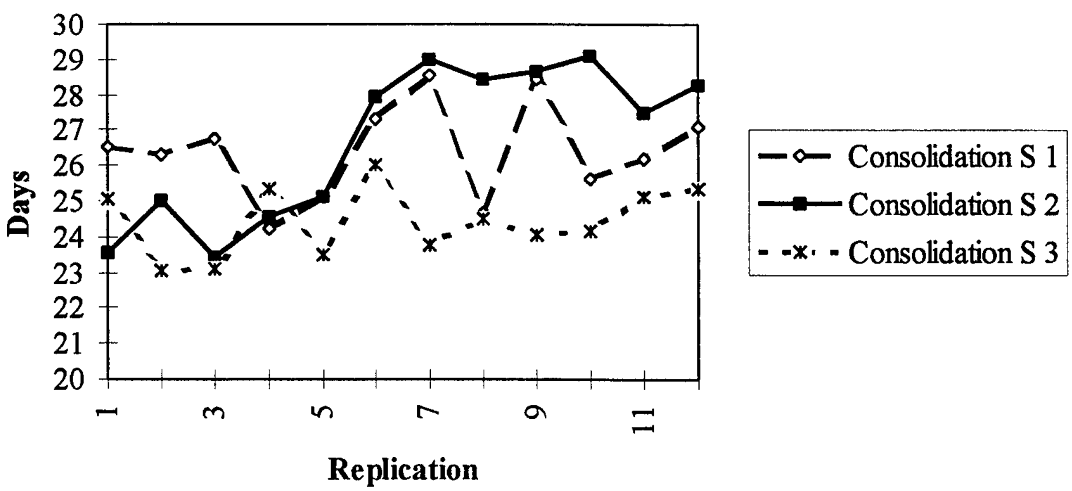

Figure C.2 All Consolidation Models, all 12 Replications

1. **Average Administrative Lead-Time Consolidation Scenario 1**

Table C.5 Average Administrative Lead-Time Scenario 1, 12 Replications

REPLICATION	CONSOLIDATION S 1
1	26.5
2	26.273
3	26.722
4	24.197
5	25.111
6	27.277
7	28.534
8	24.651
9	28.449
10	25.631
11	26.207
12	27.083

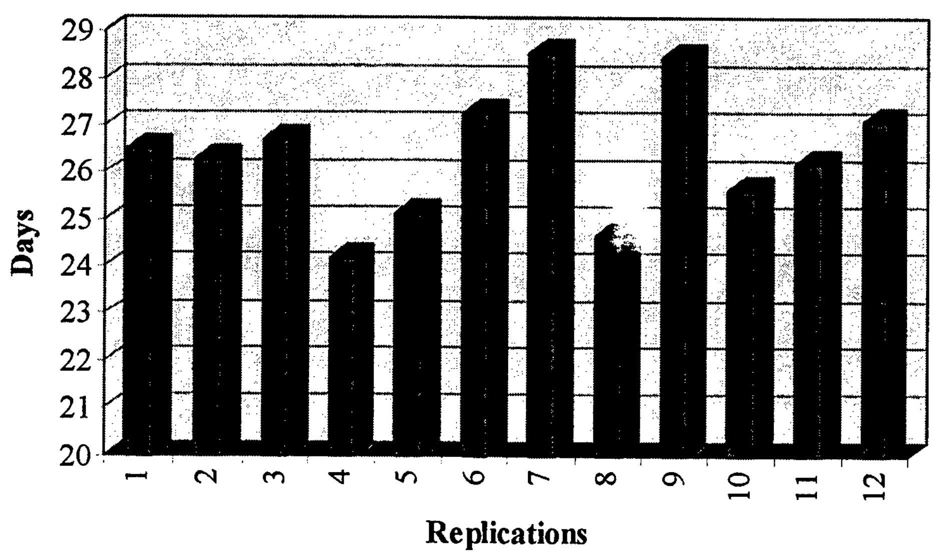

Figure C.3 Consolidation Scenario 1, all 12 Replications

2. Average Administrative Lead-Time Consolidation Scenario 2

Table C.6 Average Administrative Lead-Time Scenario 2, 12 Replications

REPLICATION	CONSOLIDATION S 2
1	23.538
2	25.023
3	23.408
4	24.523
5	25.103
6	27.907
7	28.978
8	28.448
9	28.678
10	29.075
11	27.469
12	28.237

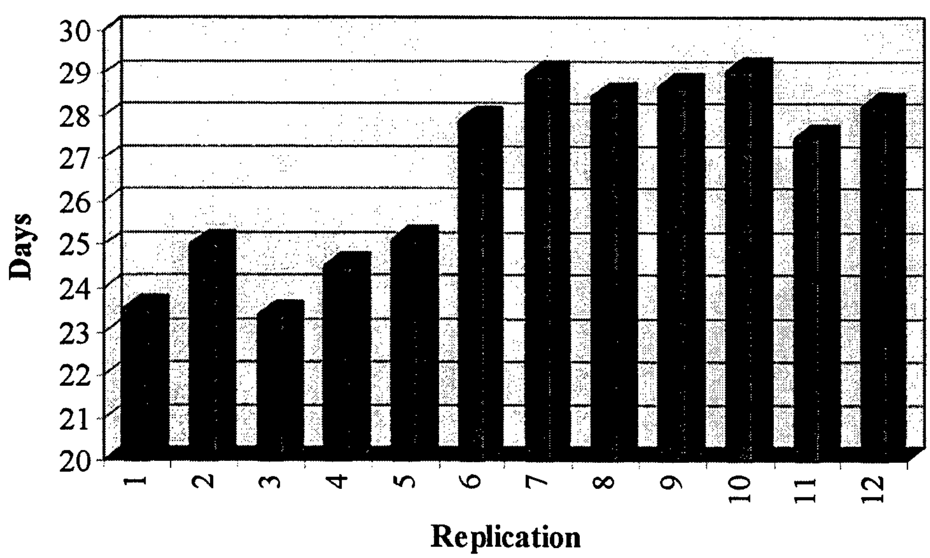

Figure C.4 Consolidation Scenario 2, all 12 Replications

3. Average Administrative Lead-Time Consolidation Scenario 3

Table C.7 Average Administrative Lead-Time Scenario 3, 12 Replications

REPLICATION	CONSOLIDATION S 3
1	25.042
2	23.011
3	23.082
4	25.365
5	23.459
6	26.002
7	23.78
8	24.507
9	24.052
10	24.13
11	25.109
12	25.344

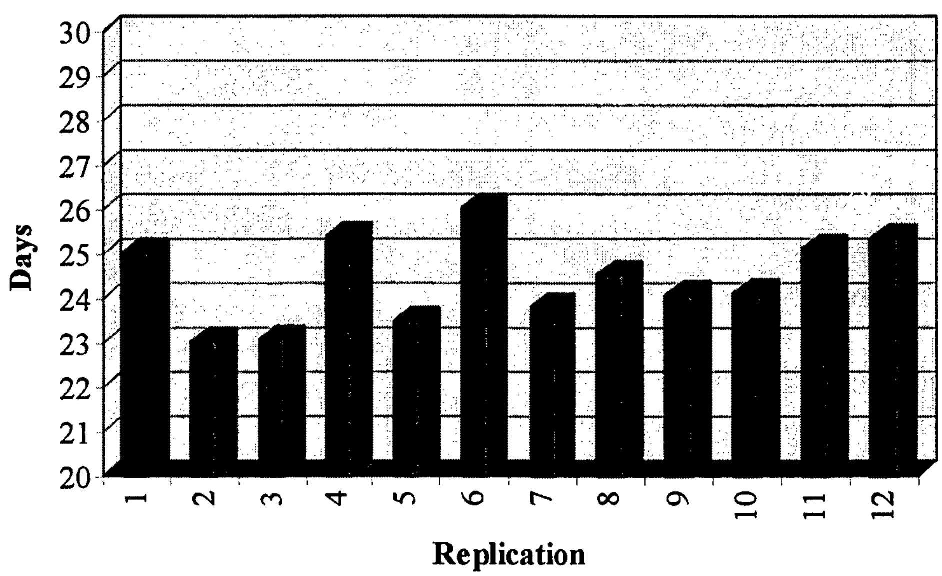

Figure C.5 Consolidation Scenario 3, all 12 Replications

D. 95 PERCENT CONFIDENCE INTERVAL ON MEAN AVERAGE LEAD-TIME

Table C.8 C.I on Administrative Lead-Time All Scenarios

IDENTIFIER	AVERAGE lead-time	LOWER 0.95 C.I	UPPER 0.95 C.I	MINIMUM lead-time	MAXIMUM lead-time
Consolidation S1	26.3	25.422	27.178	24.2	28.5
Consolidation S2	26.7	25.3	28.1	23.4	29.1
Consolidation S3	24.4	23.781	25.019	23	26

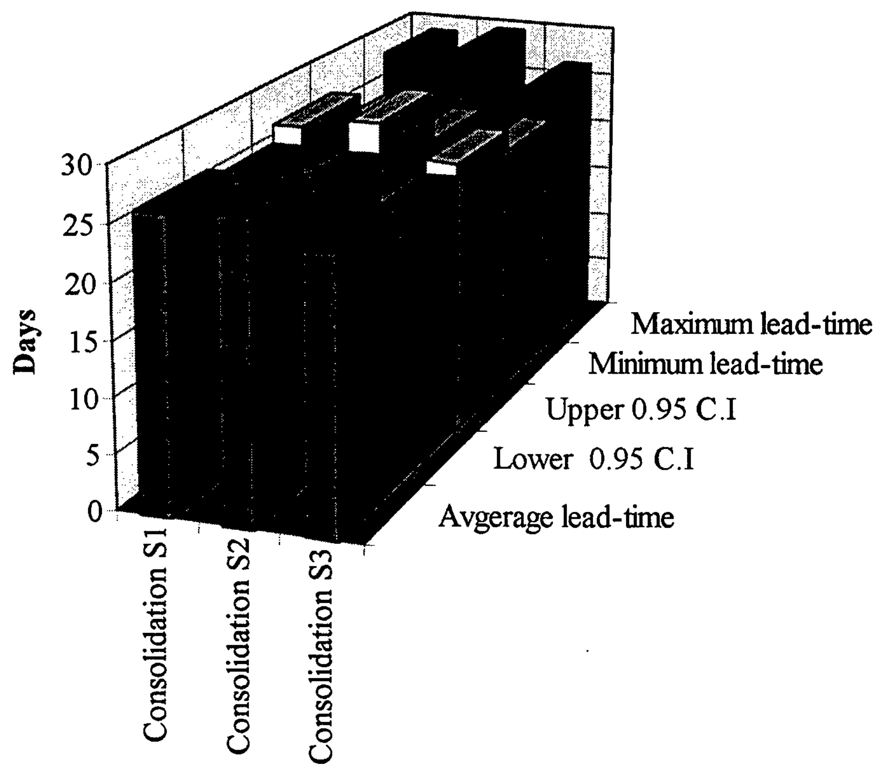

Figure C.6 95 % Confidence Interval on Mean Lead-Time Consolidation Scenarios

E. 95 PERCENT CONFIDENCE INTERVAL ON STANDARD DEVIATION OF ADMINISTRATIVE LEAD-TIME

Table C.9 C.I on Standard Deviation of Administrative Lead-Time All Scenarios

IDENTIFIER	ESTIMATED Std. Dev.	LOWER 0.95 C.I. Limit	UPPER 0.95 C.I. Limit	RANGE
Consolidation S1	1.21	0.855	2.05	4.98
Consolidation S2	1.73	1.23	2.94	4.86
Consolidation S3	0.822	0.582	1.4	2.68

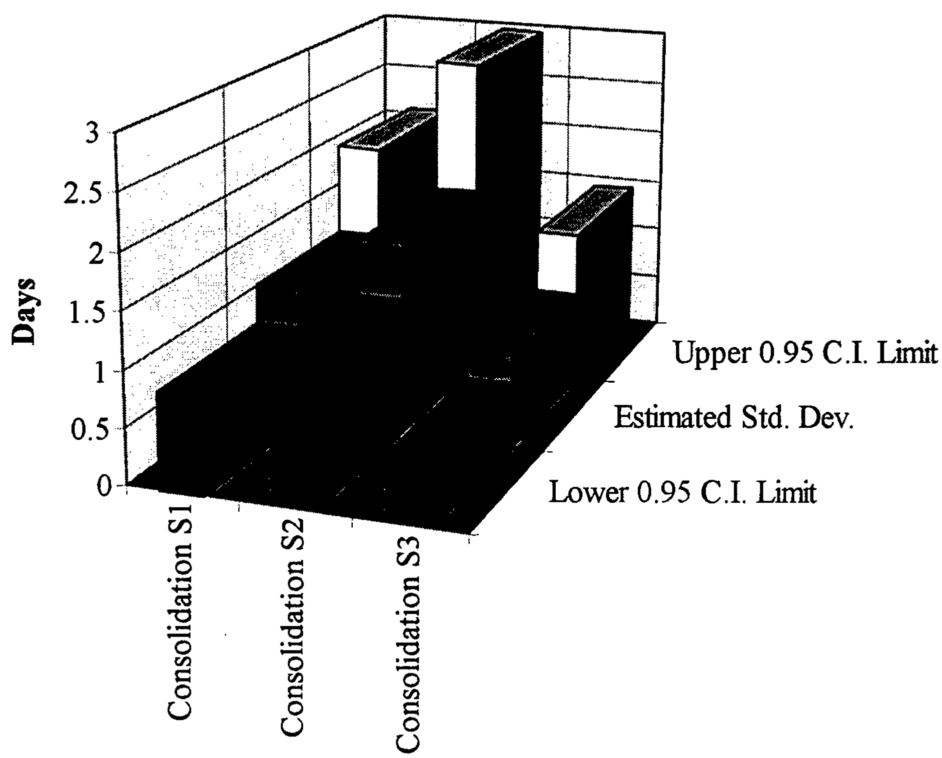

Figure C.7 95 % Confidence Interval on Standard Deviation of Lead-Time

F. PAIRED T-MEANS COMPARISON, MEAN OF SCENARIO 1 AND SCENARIO 2 COMPARED

Identifier	Minimum Observation	Maximum Observation
Scenario 1	24.2	28.5
Scenario 2	23.4	29.1

Estimated mean difference Scenario 1 and 2	-0.396
Standard Deviation	2.01
95 % Confidence Interval Half Width	1.28

FAIL TO REJECT H0 => MEANS ARE EQUAL AT 0.05 LEVEL

G. SAMPLE OUTPUT DATA FROM ARENA, CONSOLIDATION MODEL

1. Output Sample from Scenario 1

```
ARENA Simulation Results
                         Bernt E. Tysseland - License #9400000
                          Output Summary for 12 Replications
Project:  Replenishment at                  Run execution date :  11/ 5/1997
Analyst:  LCDR Bernt E Tys                  Model revision date:  11/ 5/1997
                                  OUTPUTS
```

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Avg Delay Time at Gene	2.8544	1.1617	1.0421	6.8339	12
Minimum Adm Lead Time	9.5212	.98056	6.0810	12.106	12
Avg Delay Weapon Off 1	3.6460	1.7180	.49872	10.321	12
Avg Adm Lead Time 1a	26.303	.84575	24.197	28.534	12
Avg Delay at Receiving	.01821	.00994	.00278	.06231	12
StdD Adm Lead Time 1a	9.3088	.73858	6.8663	11.843	12
Avg Delay to Enter int	.00000	.00000	.00000	.00000	12
Max Adm Lead Time 1a	55.892	4.3984	44.404	67.872	12
Avg Delay at POL Offic	3.8421	1.5607	.32291	8.7366	12
Avg Delay Hull and Ski	.00000	.00000	.00000	.00000	12
Avg Delay at Internal	.02064	.01015	.00192	.05971	12
Avg Delay at Paying Of	.01358	.00566	.00366	.02908	12
Number of Completed Re	155.66	1.5511	152.00	160.00	12
Avg Delay at Navigatio	3.1077	1.3429	.68688	7.5369	12
Avg Delay at Electroni	3.8767	1.8589	.48928	10.131	12

Simulation run time: 0.60 minutes.
Simulation run complete.

2. Output Sample from Scenario 2

ARENA Simulation Results

Bernt E. Tysseland - License #9400000

Output Summary for 12 Replications

Project: Replenishment at Run execution date : 11/ 5/1997

Analyst: LCDR Bernt E Tys Model revision date: 11/ 5/1997

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Avg Delay Time at Gene	4.3624	2.7488	.37270	13.885	12
Minimum Adm Lead Time	9.8565	.78264	7.7212	12.576	12
Avg Delay Weapon Off 1	3.5793	1.0855	.87831	6.8952	12
Avg Adm Lead Time 1b	26.699	1.3452	23.408	29.075	12
Avg Delay at Receiving	.03388	.01745	.00455	.09239	12
StdD Adm Lead Time 1b	9.8518	1.0608	7.3816	12.238	12
Avg Delay to Enter int	.00000	.00000	.00000	.00000	12
Max Adm Lead Time 1b	57.653	5.9592	46.975	74.039	12
Avg Delay at POL Offic	3.9507	2.0443	.55124	10.200	12
Avg Delay Hull and Ski	.00395	.00838	.00000	.04741	12
Avg Delay at Internal	.01357	.00637	.00000	.03029	12
Avg Delay at Paying Of	.01218	.00423	.00140	.02590	12
Number of Completed Re	155.66	1.9057	150.00	161.00	12
Avg Delay at Navigatio	4.1105	1.7411	.09630	10.091	12
Avg Delay at Electroni	4.0560	1.8448	1.1155	10.453	12

Simulation run time: 0.63 minutes.

Simulation run complete.

3. Output Sample from Scenario 3

ARENA Simulation Results

Bernt E. Tysseland - License #9400000

Output Summary for 12 Replications

Project: Replenishment at — Run execution date : 11/ 5/1997

Analyst: LCDR Bernt E Tys — Model revision date: 11/ 5/1997

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Avg Delay Time at Gene	4.0223	1.2222	1.4208	7.5075	12
Minimum Adm Lead Time	8.0438	.70104	6.4749	9.8086	12
Avg Delay Weapon Off 1	2.1786	.54825	.76861	3.7142	12
Avg Adm Lead Time 1c	24.407	.59630	23.011	26.002	12
Avg Delay at Receiving	.02113	.01368	.00400	.08264	12
StdD Adm Lead Time 1c	9.1712	.50303	8.0754	10.754	12
Avg Delay to Enter int	2.6569E-04	5.6326E-04	.00000	.00319	12
Max Adm Lead Time 1c	52.094	4.0781	44.172	66.061	12
Avg Delay at POL Offic	3.5944	1.5449	.72654	8.1745	12
Avg Delay Hull and Ski	.00148	.00314	.00000	.01777	12
Avg Delay at Internal	.01435	.00741	.00000	.03433	12
Avg Delay at Paying Of	.01478	.00497	.00384	.03134	12
Number of Completed Re	155.83	1.5837	150.00	159.00	12
Avg Delay at Navigatio	3.2140	.88164	.98974	6.2910	12
Avg Delay at Electroni	3.3258	1.0907	.82029	7.2684	12

Simulation run time: 0.62 minutes.

Simulation run complete.

APPENDIX D. ELECTRONIC COMMERCE MODEL RESULTS

A. PICTURE OF ANIMATED ELECTRONIC COMMERCE MODEL

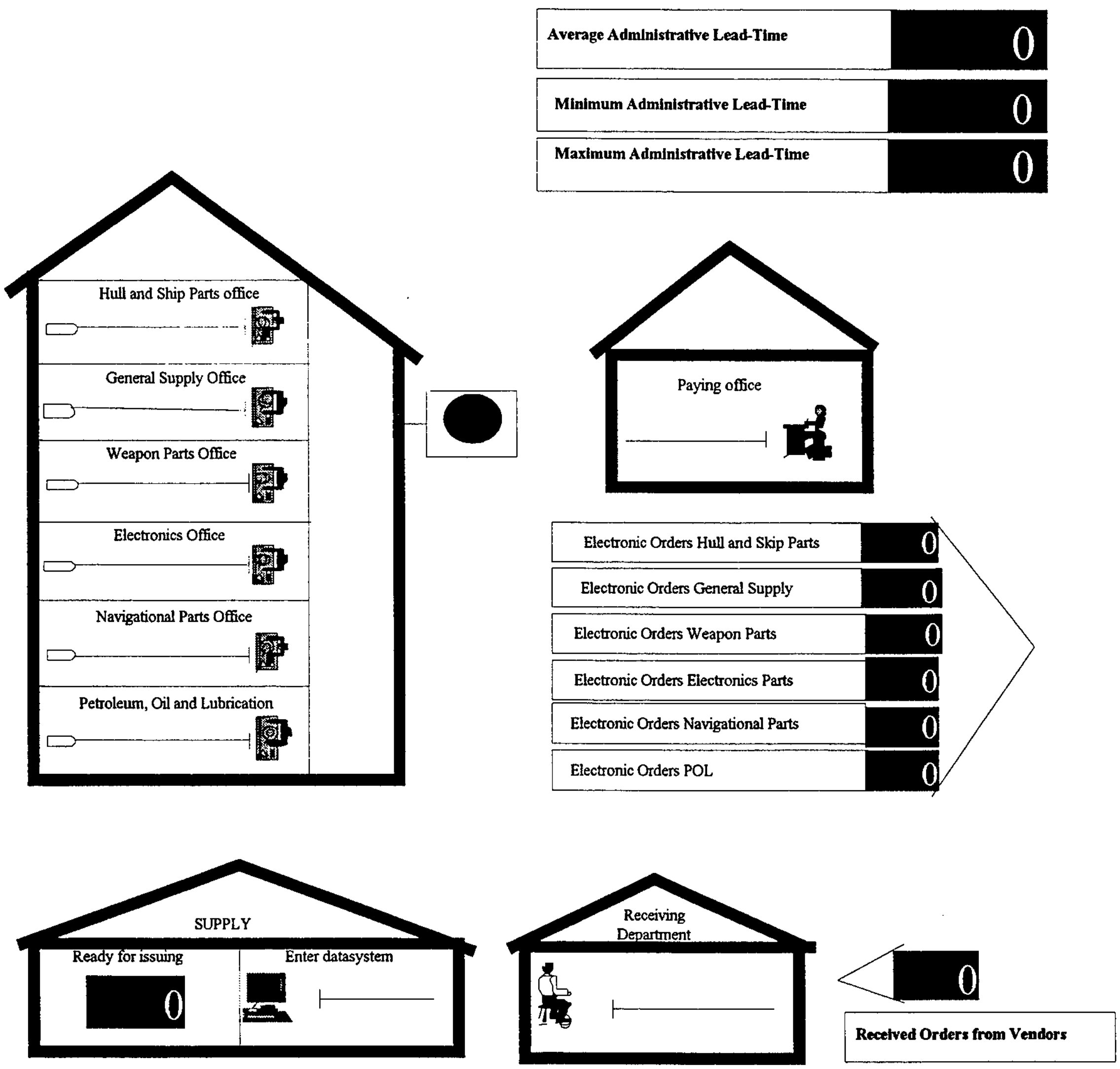

Figure D.1 Picture of Arena Animated EC Model (Scenario 1)

B. ELECTRONIC COMMERCE SCENARIO RESULTS SUMMERY

Table D.1 The Electronic Commerce Model, Scenario 1 Results

(EC MODEL SCENARIO 1)		95% C.I		
Identifier	**Average**	**Half-width**	**Minimum**	**Maximum**
Average Administrative Lead-Time	21.03	0.92343	18.687	23.953
Minimum Administrative Lead-Time	5.6742	0.47591	4.0057	6.8096
Maximum Administrative Lead-Time	49.198	5.9256	38.452	66.326
Standard Deviation of Adm Lead-Time	9.2817	0.84423	7.5729	11.863

Table D.2 The Electronic Commerce Model, Scenario 2 Results

(EC MODEL SCENARIO 2)		95% C.I		
Identifier	**Average**	**Half-width**	**Minimum**	**Maximum**
Average Administrative Lead-Time	12.147	0.21746	11.238	12.749
Minimum Administrative Lead-Time	4.8094	0.22002	3.8468	5.4153
Maximum Administrative Lead-Time	22.477	0.71658	19.404	23.797
Standard Deviation of Adm Lead-Time	3.7876	0.15439	3.2662	4.0798

Table D.3 The Electronic Commerce Model, Scenario 3 Results

(EC MODEL SCENARIO 3)		95% C.I		
Identifier	**Average**	**Half-width**	**Minimum**	**Maximum**
Average Administrative Lead-Time	10.499	0.26381	9.2851	10.962
Minimum Administrative Lead-Time	3.4359	0.27921	2.6473	4.0966
Maximum Administrative Lead-Time	20.84	0.91465	18.536	23.696
Standard Deviation of Adm Lead-Time	3.7581	0.10187	3.4639	3.9654

Table D.4 The Electronic Commerce Model, Scenario 4 Results

(EC MODEL SCENARIO 4)		95% C.I		
Identifier	**Average**	**Half-width**	**Minimum**	**Maximum**
Average Administrative Lead-Time	7.3937	0.12299	6.8911	7.7366
Minimum Administrative Lead-Time	2.9017	0.33148	2.0778	3.7354
Maximum Administrative Lead-Time	12.828	0.46411	11.277	14.343
Standard Deviation of Adm Lead-Time	2.0435	0.05131	1.9399	2.1826

C. AVERAGE ADMINISTRATIVE LEAD-TIME ALL ELECTRONIC COMMERCE SCENARIOS OVER 12 REPLICATIONS

Table D.5 Average Administrative Lead-Time, All Scenarios, 12 Replications

REPLIC.	EC SCENARIO 1	EC SCENARIO 2	EC SCENARIO 3	EC SCENARIO 4
1	20.424	12.121	10.862	7.3324
2	21.388	12.107	10.459	7.2243
3	18.687	11.238	9.2851	6.8911
4	20.121	12.027	10.379	7.4609
5	19.536	12.206	10.564	7.4825
6	20.061	12.14	10.528	7.3549
7	21.534	12.45	10.598	7.3555
8	23.339	11.973	10.33	7.4928
9	21.238	12.197	10.707	7.4905
10	20.372	12.378	10.845	7.4382
11	21.705	12.749	10.962	7.7366
12	23.953	12.177	10.465	7.4649

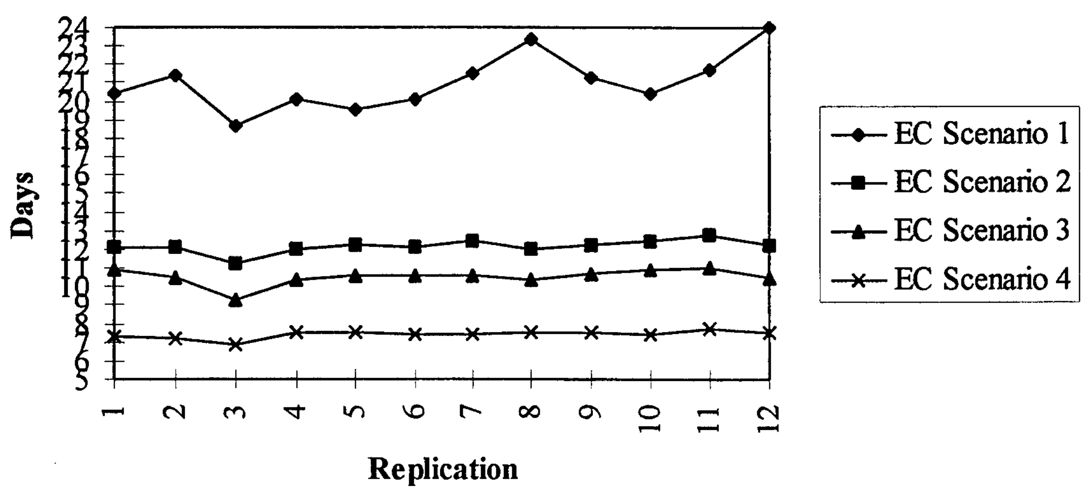

Figure D.2 Average Lead-Time All EC Scenarios, 12 Replications

1. Administrative Lead-Time EC Scenario 1

Table D.6 Average Administrative Lead-Time, Scenario 1, 12 Replications

REPLICATION	EC SCENARIO 1
1	20.424
2	21.388
3	18.687
4	20.121
5	19.536
6	20.061
7	21.534
8	23.339
9	21.238
10	20.372
11	21.705
12	23.953

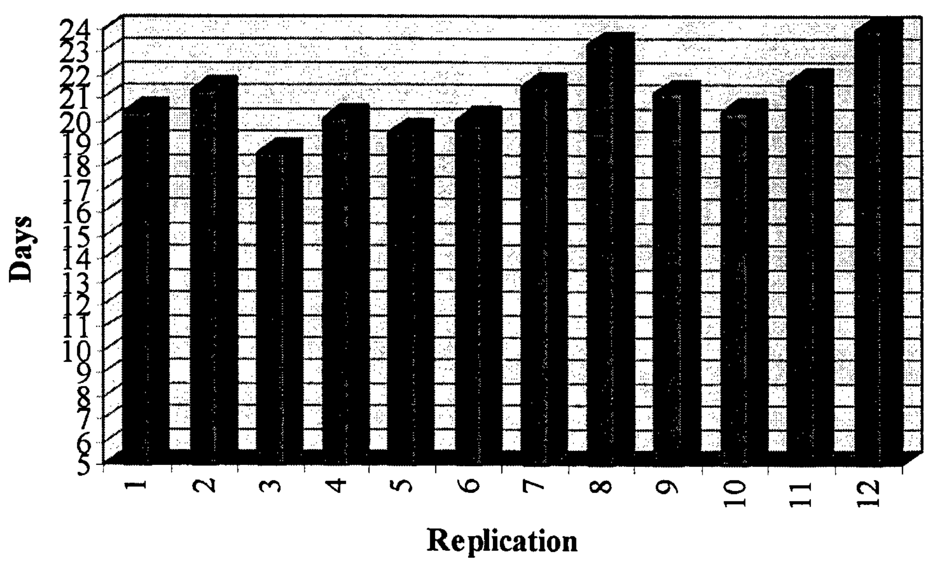

Figure D.3 Average Lead-Time EC Scenario 1, 12 Replications

2. Administrative Lead-Time EC Scenario 2

Table D.7 Average Administrative Lead-Time, Scenario 2, 12 Replications

REPLICATION	EC SCENARIO 2
1	12.121
2	12.107
3	11.238
4	12.027
5	12.206
6	12.14
7	12.45
8	11.973
9	12.197
10	12.378
11	12.749
12	12.177

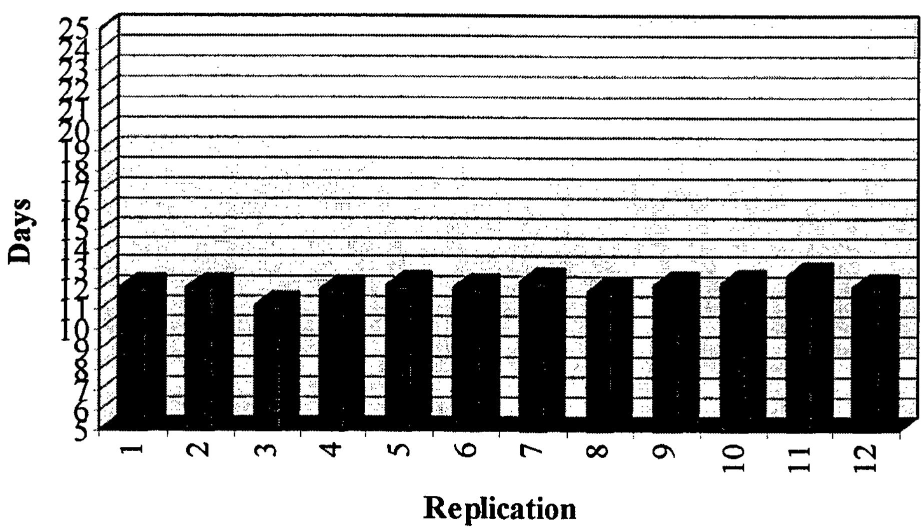

Figure D.4 Average Lead-Time EC Scenario 2, 12 Replications

3. Administrative Lead-Time EC Scenario 3

Table D.8 Average Administrative Lead-Time, Scenario 3, 12 Replications

REPLICATION	EC SCENARIO 3
1	10.862
2	10.459
3	9.2851
4	10.379
5	10.564
6	10.528
7	10.598
8	10.33
9	10.707
10	10.845
11	10.962
12	10.465

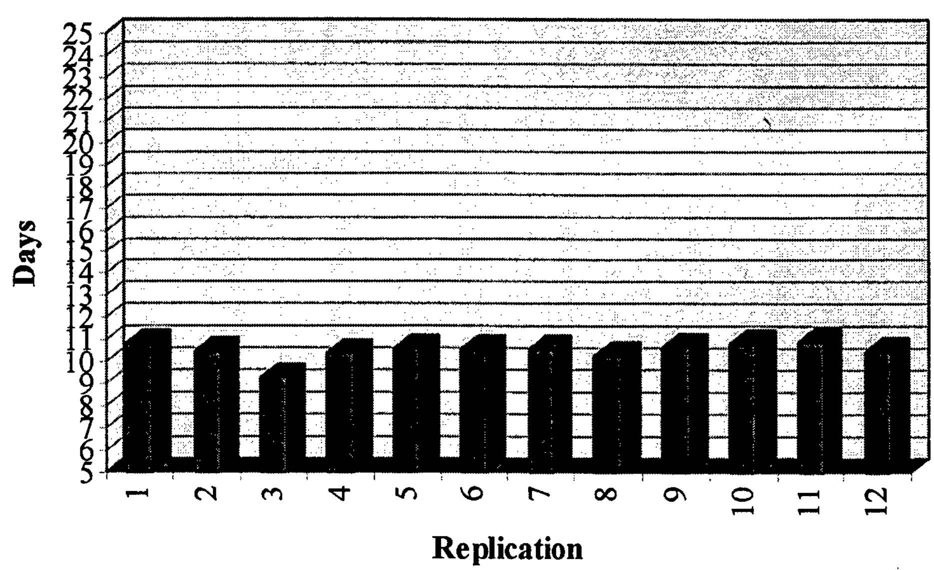

Figure D.5 Average Lead-Time EC Scenario 3, 12 Replications

4. Administrative Lead-Time EC Scenario 4

Table D.9 Average Administrative Lead-Time, Scenario 4, 12 Replications

REPLICATION	EC SCENARIO 4
1	7.3324
2	7.2243
3	6.8911
4	7.4609
5	7.4825
6	7.3549
7	7.3555
8	7.4928
9	7.4905
10	7.4382
11	7.7366
12	7.4649

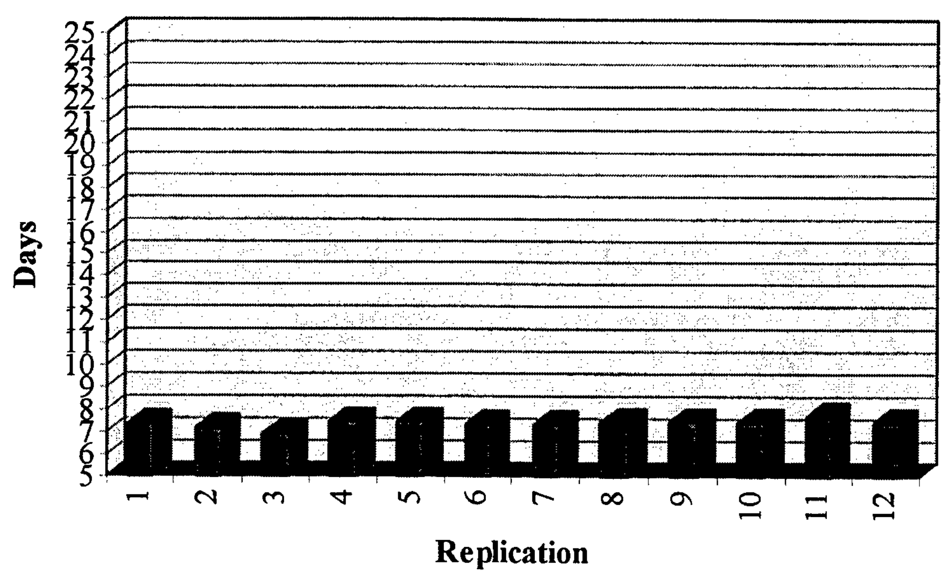

Figure D.6 Average Lead-Time EC Scenario 4, 12 Replications

D. 95 PERCENT CONFIDENCE INTERVAL ON MEAN AVERAGE LEAD-TIME

Table D.10 C.I. on Administrative Lead-Time, All Scenarios

IDENTIFIER	AVERAGE lead-time	LOWER 0.95 C.I	UPPER 0.95 C.I	MINIMUM lead-time	MAXIMUM lead-time
EC Scenario 1	21	20.041	21.959	18.7	24
EC Scenario 2	12.1	11.874	12.326	11.2	12.7
EC Scenario 3	10.5	10.226	10.774	9.29	11
EC Scenario 4	7.39	7.262	7.518	6.89	7.74

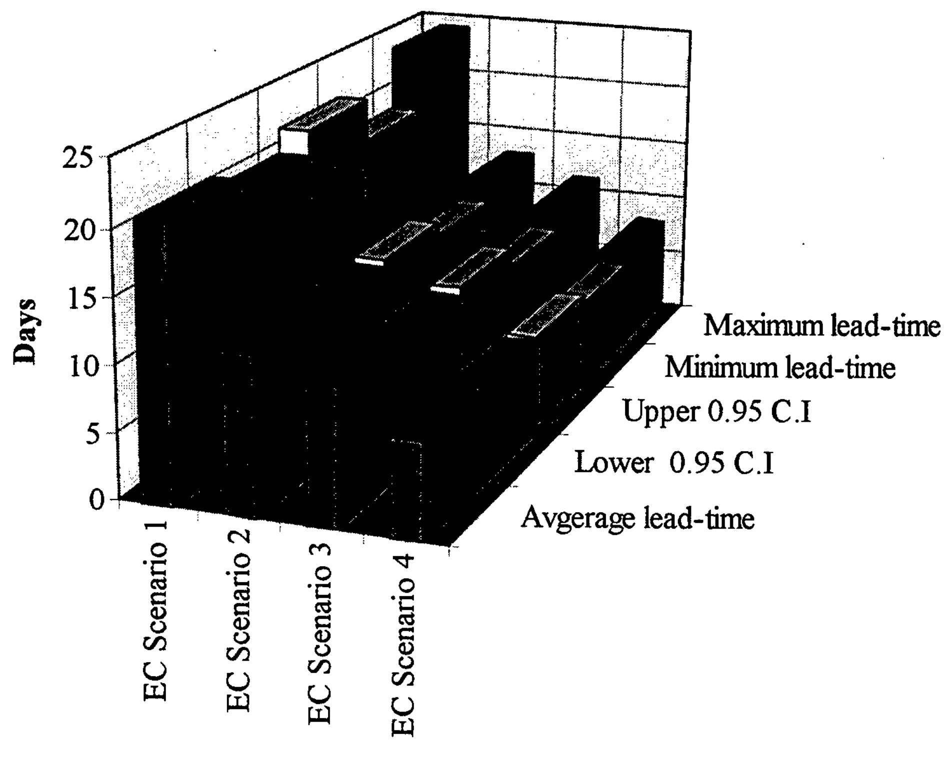

Figure D.7 95 % C.I. on Mean Lead-Time All EC Scenarios

E. 95 PERCENT CONFIDENCE INTERVAL ON STANDARD DEVIATION OF ADMINISTRATIVE LEAD-TIME

Table D.11 C.I. on Standard Deviation of Administrative Lead-Time, All Scenarios

IDENTIFIER	ESTIMATED Std. Dev.	LOWER 0.95 C.I. Limit	UPPER 0.95 C.I. Limit	RANGE
EC Scenario 1	1.38	0.977	2.34	4.29
EC Scenario 2	0.252	0.179	0.428	0.814
EC Scenario 3	0.166	0.118	0.283	0.501
EC Scenario 4	0.0838	0.0594	0.142	0.243

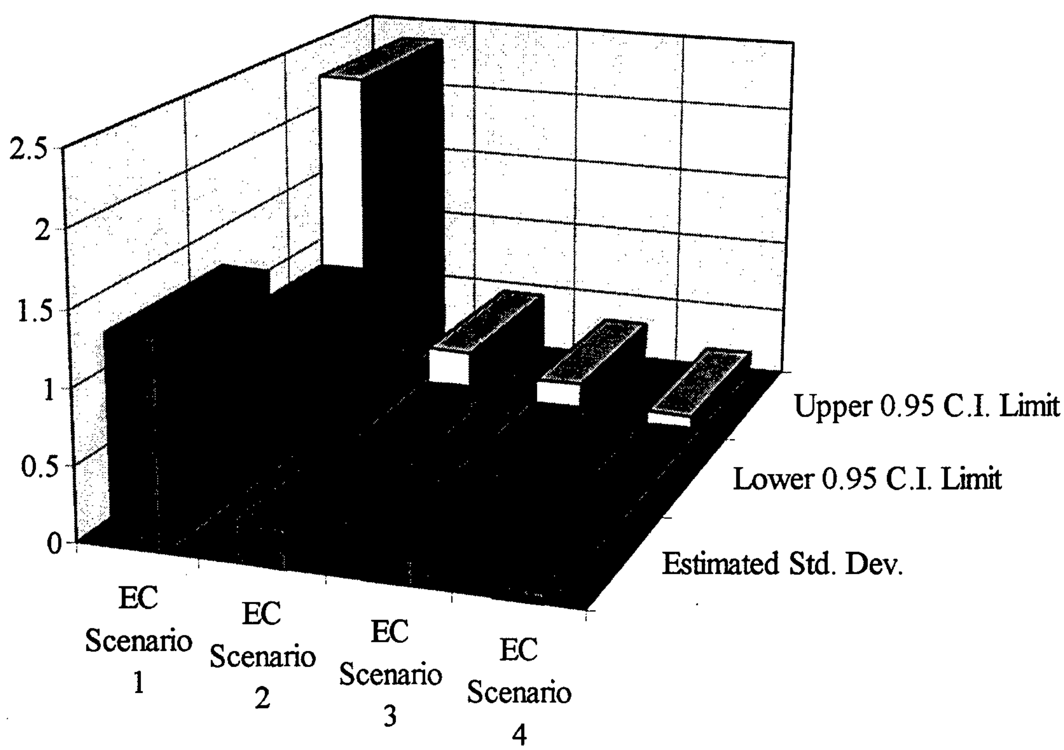

Figure D.8 95 % C.I. on Standars Deviation of Lead-Time All EC Scenarios

F. SAMPLE OUTPUT DATA FROM ARENA, ELECTRONIC COMMERCE MODEL

1. Output Sample from Scenario 1

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ARENA Simulation Results
                      Bernt E. Tysseland - License #9400000
                       Output Summary for 12 Replications

Project:  Replenishment at                    Run execution date :  11/ 5/1997
Analyst:  LCDR Bernt E Tys                    Model revision date:  11/ 5/1997
                                    OUTPUTS
Identifier              Average    Half-width Minimum    Maximum # Replications
-------------------------------------------------------------------------------
Minimum Adm Lead Time  5.6742     .47591     4.0057     6.8096     12
Avg Delay Time at Gene 4.9040     2.3842     1.5197     13.675     12
Avg Delay Weapon Off 2 3.0310     1.0171     .49126     6.2513     12
Avg Adm Lead Time 2a   21.030     .92343     18.687     23.953     12
StdD Adm Lead Time 2a  9.2817     .84423     7.5729     11.863     12
Avg Delay at Receiving .03436     .01302     .00779     .07877     12
Avg Delay to Enter int .00000     .00000     .00000     .00000     12
Max Adm Lead Time 2a   49.198     5.9256     38.452     66.326     12
Avg Delay at POL Offic 2.5029     .97166     1.0640     6.6003     12
Avg Delay Hull and Ski 4.8419     1.9821     1.1543     11.356     12
Avg Delay at Paying Of .02085     .00964     .00360     .05675     12
Avg Delay at Navigatio 4.0271     1.4225     1.3643     8.4164     12
Number of Completed Re 155.91     1.9433     148.00     161.00     12
Avg Delay at Electroni 2.7817     .86165     1.2282     5.4614     12

Simulation run time: 0.50 minutes.
Simulation run complete.
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2. Output Sample from Scenario 2

ARENA Simulation Results

Bernt E. Tysseland - License #9400000

Output Summary for 12 Replications

Project: Replenishment at — Run execution date : 11/ 5/1997

Analyst: LCDR Bernt E Tys — Model revision date: 11/ 5/1997

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Avg Delay Time at Gene	.00169	.00358	.00000	.02029	12
Minimum Adm Lead Time	4.8094	.22002	3.8468	5.4153	12
Avg Delay Weapon Off 2	.00279	.00591	.00000	.03344	12
Avg Adm Lead Time 2b	12.147	.21746	11.238	12.749	12
Avg Delay at Receiving	.03286	.01363	.01660	.08578	12
StdD Adm Lead Time 2b	3.7876	.15439	3.2662	4.0798	12
Avg Delay to Enter int	.00000	.00000	.00000	.00000	12
Max Adm Lead Time 2b	22.477	.71658	19.404	23.797	12
Avg Delay at POL Offic	.00182	.00338	.00000	.01919	12
Avg Delay Hull and Ski	.00000	.00000	.00000	.00000	12
Avg Delay at Paying Of	.01775	.00820	.00250	.04991	12
Number of Completed Re	156.50	1.0273	154.00	160.00	12
Avg Delay at Navigatio	.00254	.00318	.00000	.01679	12
Avg Delay at Electroni	.00116	.00246	.00000	.01392	12

Simulation run time: 0.53 minutes.

Simulation run complete.

3. Output Sample from Scenario 3

ARENA Simulation Results

Bernt E. Tysseland - License #9400000

Output Summary for 12 Replications

Project: Replenishment at — Run execution date : 11/ 5/1997

Analyst: LCDR Bernt E Tys — Model revision date: 11/ 5/1997

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Avg Delay Time at Gene	.00116	.00246	.00000	.01392	12
Minimum Adm Lead Time	3.4359	.27921	2.6473	4.0966	12
Avg Delay Weapon Off 2	7.4061E-04	.00157	.00000	.00889	12
Avg Adm Lead Time 2c	10.499	.26381	9.2851	10.962	12
Avg Delay at Receiving	.03629	.01357	.00510	.08821	12
StdD Adm Lead Time 2c	3.7581	.10187	3.4639	3.9654	12
Avg Delay to Enter int	3.4436E-05	7.3004E-05	.00000	4.1323E-04	12
Max Adm Lead Time 2c	20.840	.91465	18.536	23.696	12
Avg Delay at POL Offic	.00311	.00587	.00000	.03344	12
Avg Delay Hull and Ski	.00160	.00339	.00000	.01919	12
Avg Delay at Paying Of	.00000	.00000	.00000	.00000	12
Number of Completed Re	156.50	.76080	155.00	159.00	12
Avg Delay at Navigatio	.00256	.00388	.00000	.02029	12
Avg Delay at Electroni	.00000	.00000	.00000	.00000	12

Simulation run time: 0.53 minutes.
Simulation run complete.

4. Output Sample from Scenario 4

ARENA Simulation Results

Bernt E. Tysseland - License #9400000

Output Summary for 12 Replications

Project: Replenishment at — Run execution date : 11/ 5/1997

Analyst: LCDR Bernt E Tys — Model revision date: 11/ 5/1997

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Avg Delay Time at Gene	.00000	.00000	.00000	.00000	12
Minimum Adm Lead Time	2.9017	.33148	2.0778	3.7354	12
Avg Delay Weapon Off 2	.00000	.00000	.00000	.00000	12
Avg Adm Lead Time 2d	7.3937	.12299	6.8911	7.7366	12
Avg Delay at Receiving	.24705	.02902	.17292	.31533	12
StdD Adm Lead Time 2d	2.0435	.05131	1.9399	2.1826	12
Avg Delay to Enter int	.00129	.00162	.00000	.00886	12
Max Adm Lead Time 2d	12.828	.46411	11.277	14.343	12
Avg Delay at POL Offic	.00000	.00000	.00000	.00000	12
Avg Delay Hull and Ski	.00000	.00000	.00000	.00000	12
Avg Delay at Paying Of	6.4223E-05	1.3615E-04	.00000	7.7068E-04	12
Number of Completed Re	156.50	.99368	154.00	160.00	12
Avg Delay at Navigatio	.00000	.00000	.00000	.00000	12
Avg Delay at Electroni	.00000	.00000	.00000	.00000	12

Simulation run time: 0.52 minutes.

Simulation run complete.

APPENDIX E. SAMPLE DATA AND SUMMARY FROM THE NORWEGIAN NAVY MATERIEL COMMAND'S C-MODEL

SKU	Nato Stock Number	M (max)	Reorder	War Res	On hand	Price NOK	MAD	Inventory
4050	8455251446523	382	68	0	379	15.38	26.04	5829.02
4051	8455251452729	551	123	0	1053	100	87.24	105300
4052	8455251452730	677	87	0	101	160	62.52	16160
4053	8455251452731	943	342	0	171	170	53.6	29070
4054	8455251452732	1250	580	0	191	180	55.1	34380
4055	8455251452733	785	305	0	515	180	44.62	92700
4056	8455251452734	360	156	0	389	200	18.46	77800
4057	8455251452735	207	101	0	120	200	10.51	24000
4058	8455251452736	86	38	0	123	200	4.87	24600
4059	8455251468697	2739	1539	0	9240	5.5	1300	50820
4060	8455258292641	2890	797	0	56644	5	340.26	283220
4061	8460251200529	29	16	0	47	750	1.4	35250
4062	8465121735474	70	12	0	0	153	12.12	0
4063	8465223074654	108	60	0	37	5.86	4.84	216.82
4064	8465251053213	26	7	0	0	650.66	2.71	0
4065	8465251244622	2679	2631	0	0	60	176.56	0
4066	8465258296001	1296	720	0	5220	1	148.12	5220
4067	8470123262569	95	76	0	0	1725	2.02	0
4068	8470123262570	929	780	0	0	1725	14.34	0
4069	8470123262571	441	352	0	0	1725	8.96	0
4070	8470123262572	122	103	0	0	1725	2.1	0
4071	8520251161462	23012	961	0	5000	1.02	1545.67	5100
4072	8520251408745	419	35	0	241	34.93	70.28	8418.13
4073	8530251094801	5691	821	0	1705	7.54	563.92	12855.7
4074	8540250007630	269	66	0	110	27.31	61.81	3004.1
4075	8540251151101	160	4	0	40	254.86	13.2	10194.4
4076	8540251253536	11107	512	0	2234	18.55	526.53	41440.7
4077	8540251253537	2133	79	0	650	48.34	37.59	31421
4078	8540251412430	85	37	0	97	116.27	20.96	11278.19
4079	8540251412472	50	12	0	88	111.59	9.54	9819.92

4080	9150006982382	24	2	0	5	19.73	3.58	98.65
4081	9150013585154	23	4	0	13	492	2.08	6396
4082	9150121245783	43	6	0	51	201.3	1.48	10266.3
4083	9150121297233	51	20	0	34	714.63	4.96	24297.42
4084	9150121973599	52	4	0	0	822.87	5	0
4085	9150129100885	43	5	0	0	341.6	4	0
4086	9150170328841	33	4	0	13	95.57	3.22	1242.41
4087	9150176220060	299	31	0	484	46.36	17.5	22438.24
4088	9150177002860	29	10	0	28	73.8	2.89	2066.4
4089	9150219075982	47	6	0	150	29.52	3.56	4428
4090	9150251012789	242	38	0	0	65.88	19.16	0
4091	9150251024646	116	27	0	112	47.66	7.81	5337.92
4092	9150251025140	16	6	0	5	309.96	1.86	1549.8
4093	9150251025953	42	20	0	137	28.06	7.23	3844.22
4094	9150251025979	15	5	0	38	78.11	2.11	2968.18
4095	9150251068327	34	5	0	0	39.04	2.76	0
4096	9150251145074	164	19	0	109	255.84	5.77	27886.56
4097	9150251145234	310	46	0	106	15.07	16	1597.42
4098	9150251145355	641	35	0	0	22.78	25.02	0
4099	9150251145356	224	24	0	83	35.88	14.84	2978.04
4100	9150251145371	138	7	0	39	252.15	9.71	9833.85
4101	9150251151591	34	4	0	19	243.54	2.22	4627.26
4102	9150251160532	37	7	0	24	55.67	3.41	1336.08
4103	9150251280365	33	4	0	6	147.6	2.74	885.6
4104	9150251300574	33	4	0	5	22.16	3	110.8
4105	9150251339466	113	6	0	15	72.1	10.9	1081.5
4106	9150251400978	24	5	0	29	59.66	2.16	1730.14
4107	9150251434322	64	6	0	25	1375.43	5.72	34385.75
4108	9150251442384	116	49	0	0	392.99	8.63	0
4109	9150251456430	33	4	0	10	638.37	3.22	6383.7
4110	9160223074652	214	29	0	26	25.22	15.33	655.72
4111	9160251337371	67	17	0	36	8.91	5.79	320.76
4112	9320121438929	12	0	0	6	41.82	0.96	250.92
4113	9320121490394	47	4	0	32	40.47	3.4	1295.04
4114	9330123197096	28	9	0	18	49.2	2	885.6
4115	9330123197099	13	2	0	7	39.36	0.7	275.52
4116	9330123197100	15	3	0	10	86.1	1.65	861
4117	9330123197104	17	0	0	0	301.35	2.48	0

4118	9330123197107	25	12	0	16	38.13	1.45	610.08
4119	9330251096367	151	9	0	22	134.07	6.2	2949.54
4120	9330251237329	3006	265	0	101	29.77	98.61	3006.77
4121	9330251345104	181	15	0	500	0.71	19.23	355
4122	9330251345105	2076	480	0	600	0.71	288.24	426
4123	9330251345107	105	28	0	300	1.73	12.4	519
4124	9330251380526	21	4	0	9	290.28	2.9	2612.52
4125	9330251396368	11	0	0	11	56.58	1.13	622.38
4126	9330251413198	14	0	0	0	135.55	0.8	0
4127	9390251096249	3139	1583	0	2113	14.64	140.6	30934.32
4128	9390251457186	104	27	0	290	7.49	9	2172.1
4129	9390251457187	372	55	0	240	7.61	31.33	1826.4
4130	9510251428109	33	1	0	54	41.58	2.96	2245.32
4131	9510251428110	33	4	0	25	42.9	2.84	1072.5
4132	9510251428111	33	4	0	63	42.9	3	2702.7
4133	9510251428112	42	4	0	19	41.89	3.92	795.91
4134	9525251012518	366	88	0	2000	0.18	29	360
4135	9525251068238	2424	811	0	6400	0.04	176.17	256
4136	9905251013866	5303	1185	0	2160	2	452.06	4320
4137	9905251132622	35	6	0	31	38.13	3.17	1182.03
4138	9905251132623	13	3	0	22	37.88	1.58	833.36
4139	9905251132624	36	7	0	32	38.13	3	1220.16
4140	9905251132625	12	2	0	5	39.36	1.12	196.8
4141	9905251132632	15	2	0	1	29.28	1.83	29.28
4142	9905251132635	23	4	0	36	31.98	1.97	1151.28
4143	9905251132639	23	4	0	34	40.59	2.17	1380.06
4144	9905251132640	33	4	0	17	31.98	3.48	543.66
4145	9905251132644	26	4	0	5	34.81	1.87	174.05
4146	9905251132645	12	2	0	22	37.82	1.45	832.04
4147	9905251132646	34	5	0	12	31.72	4.23	380.64
4148	9905251132647	17	7	0	48	34.81	2.28	1670.88
4149	9905251132648	54	6	0	6	31.72	6.48	190.32
4150	9905251132650	23	12	0	28	37.82	4.08	1058.96
4151	9905251132657	96	19	0	50	35.67	10.81	1783.5
4152	9905251132667	14	4	0	18	37.82	1.07	680.76
4153	9905251132673	52	4	0	14	29.28	4.96	409.92
4154	9905251160593	14	2	0	10	92.25	2.09	922.5
4155	9905251310719	14	4	0	28	36.6	1.05	1024.8

4156	9905251310722	14	4	0	19	40.8	1.03	775.2
4157	9905251317612	35	6	0	120	24.4	3.92	2928
4158	9905251380152	80	37	0	75	28.29	14.25	2121.75
4159	9905251380153	61	15	0	95	19.63	7.39	1864.85
	Sum	1238189	243533	513	1493861	1214918	109138	64244937

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